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A DYNAMO SIMULATION OF
AN ASSAULT RIVER CROSSING

A THESIS

Presented to

The Faculty of the Graduate Division

by

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A DYNAMO SIMULATION OF

AN ASSAULT RIVER CROSSING

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CHAPTER I

INTRODUCTION

Statement of Objectives

This thesis embodies two distinct projects. One is a literature search into the general area of war gaming and military digital simulation, followed by the study of several specific military simulation programs. The first project is reported in Chapters I and II. The second project takes a specific military problem, builds a simulation model in the Dynamo computer language, and conducts an investigation of the problem through the means of simulation experiments. The problem of interest deals with the following aspects of a mechanized infantry division in the execution of an assault river crossing:

a. Given a particular set of crossing equipment, a comparison of several possible crossing plans will be made to determine which plan best satisfies the major requirements of the division's stated tactical plan.

b. Decision criteria relative to the forward movement rate of troop units, and the density of troop concentration throughout the division zone, constitute the control measures which will govern the crossing. These decision criteria should insure a full utilization of crossing capabilities while minimizing the presentation of worthwhile targets to attack by enemy fire. The objective will be to determine the decision policies which best satisfy the above requirements.

The report of this research is presented in the Chapters III through V which deal with the tactical problem, the simulation models, and the research results and analysis, respectively.

The Nature of Current Military Problems

The study of modern warfare presents a seemingly endless number of complex problems which at first glance seem to confound analytic solution. Modern technology has provided military forces with capabilities of communication, mobility and firepower which stagger the imagination. Military problems are further complicated by the continuous advancement of this technology and by the nature of war itself. Conflict situations are characterized by uncertainty and their description involves a large number of relevant variables and parameters which are generally probabilistic, dynamic and non-linear in their inter-relationship.

To fully describe the nature of current military problems would be a most extensive study within itself. However, it is possible to briefly relate the general nature of several paramount problem areas. In tactical decision-making, commanders are confronted with choosing a force composition from the forces available, and specifying a course of action as to maneuver, fire and logistical support plans, from among a number of feasible alternatives. This is done with the goal of choosing the task organization and course of action that promise the greatest probability of success. Similarly, service schools and other military agencies address themselves to this same problem area with the objective of developing tactical doctrine that is regarded as "optimal" in a given situation. The current and future organization of military units is subject to continuous study which seeks the so called optimal mix of weapons systems, other mission-essential equipment and variously trained personnel along with a command and control system which is deemed both "most effective" and "most efficient"; all this must be weighed against a number of likely missions which the unit is to be capable of accomplishing. In the evaluation of weapon systems choices must be made between alternatives, often of weapons not yet developed for organizations that are presently conceptual. Engineering analysis of an alternative weapon system's design characteristics will provide only a partial answer. The competitive systems must be compared within the context of a conceptual organization and tactical environment as to the unit and weapon missions, logistical support requirements, time frames of development and utilization, and overall costs. Finally, as a point of emphasis, let us briefly consider the logistical problem areas of a modern military force. Viewed as an entity the problems of logistical support are massive. Requirements must be determined, ultimately in the greatest detail; logistical support systems must be designed and created which fulfil the requirements, hopefully at a minimal overall cost; decisions must be made for every echelon as to its internal support capabilities and then the external support requirements must be determined and provided; the composition of every logistical support unit must be determined, specifying the equipment, tools, trained personnel and administrative control structure that are required; and finally the integrated workings of the "whole system" must be defined in terms of the policies and procedures which govern every aspect of providing the logistical user with the supplies, maintenance, transportation and medical support that are required.

Some Solution Techniques

As in the solution of complex engineering and industrial problems, a number of problem solving techniques are used in dealing with the more difficult problems of a military nature. Field training exercises provide a source from which data can be collected for analysis and evaluation. However, the results of such exercises are very difficult to analyze scientifically. Without a real enemy and real casualties the exercise environment lacks realism. Compensation for the lack is hopefully gained through the use of human controllers and umpires. However, even this control measure renders subjective results that are likely to be inaccurate and biased. This obvious disadvantage has led to field experimentation such as that performed by HUMRO (Human Research Organization) and CDEC (Combat Developments Experimentation Center) (2), where field exercises are especially designed as scientifically controlled experiments with the data for analysis and evaluation being collected by trained observers. Such experiments are probably preferable to the simple observations of field training exercises, though even with careful design the dangers of subjective results are still present and appreciable expense is incurred in providing field experimentation (2, 29). Command post exercises, which are used to a great extent for training purposes, can also provide a vehicle for military systems analysis. This is particularly true if they are two-sided exercises which give the enemy his due as a capable and obnoxious adversary. Again the results are subjective in nature, although the dangers of subjectivity can be more effectively controlled through the use of extensive exercise rules by a trained controller staff. This approach tends to make command post exercises slow-moving and somewhat cumbersome. Nonetheless, such exercises, which border on manual simulation, have proven to be worth the effort in a number of military problem areas, affording reasonable estimates to be made of some of the major parameters involved in particular problems (20, 29, 34). Military experience in the form of historical data provides another frequently used source of information for military operations research. This store of information is most extensive and much of it is useful. However, such data must obviously be used with care, as it is generally subjective and relates to the past with the accompanying dangers of inaccuracy, incompleteness and bias along with the added difficulty of extrapolation into the future.

War Gaming

War gaming has a centuries old history of respectability among professional soldiers. It most probably began with the Chinese General Sun Tzu (37) who conducted mock military operations with scribblings in the sand for the purpose of analyzing all the facets of a likely military encounter. In attempting to work out the various actions that could be taken by the enemy and his own forces, Sun Tzu examined the moves that he could make against all the moves his enemy might do to oppose him. Beginning in the 18th century games came to be used for the additional purpose of training professional officers in the art of war. First came the rigid Kriegsspiel and thereafter its free form (34). The German interest in war gaming continued from this time and was used extensively prior to and during both World Wars, not only for training purposes but also for the gaming evaluation of actual operational plans (34).

Beginning with von Neumann in 1928 a formalized mathematical game theory has evolved through the works of Morgenstern (30), McKinsey (27), Williams (38), Karlin (23), Dresher (14), Dalkey (6, 7) and others. Though there has been some useful application, chiefly by the Rand Corporation, of formalized game theory to military problems, it has to date been very limited in scope (6, 34).

As implied, a war game is simply an analytical method of attacking a complex military problem. We can further define war gaming along with its objectives in terms of a model loop (Figure 1). Operational games are designed to test war plans. They deal with weapons, organizations, and doctrine that are in being. These coupled with a specific likely military situation provide inputs that are generally known quantities. The realization from this type game provides a basis of decision for the approval or revision of current war plans. Research games are used to analyze and evaluate conceptual weapons systems, organizations and doctrine. The inputs are therefore a matter of conjecture, and it is generally thought that such games should test one element or a few elements which do not strongly influence one another. Training games are designed to train commanders and staff officers by leading them through a series of decision making processes. The training game can be less rigid and its input less precise than in the previous two games defined, as long as a sufficient level of realism can be attained to provide a beneficial training experience.

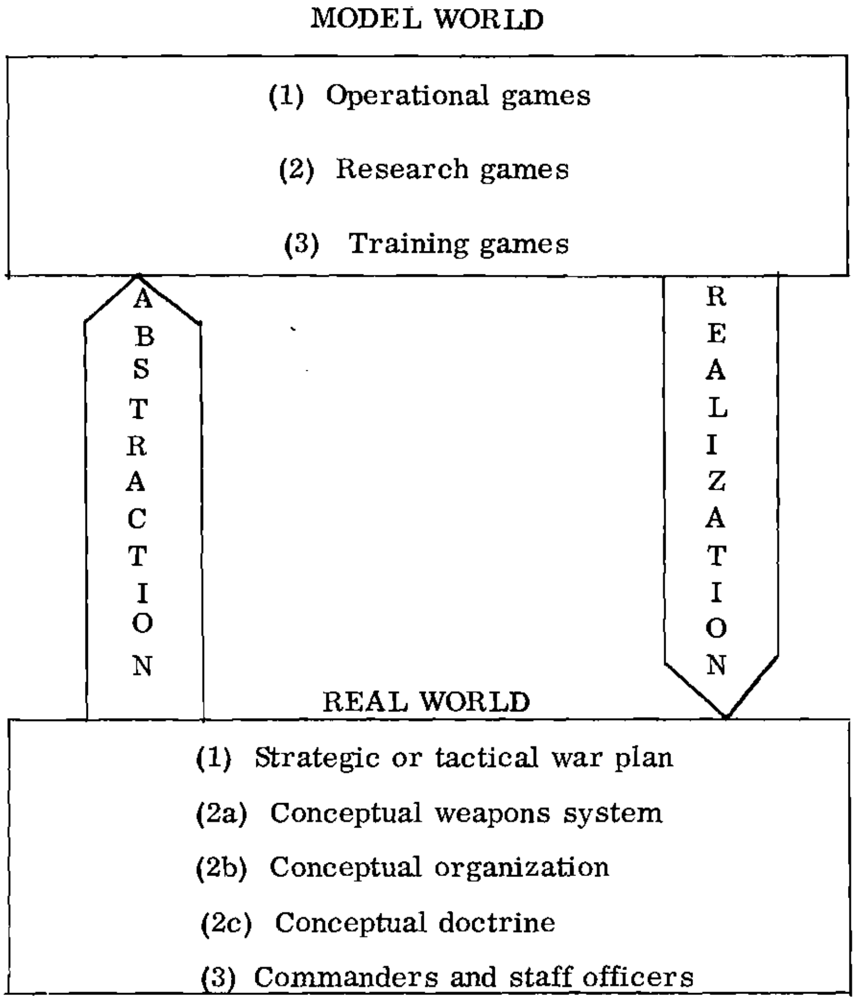

Figure 1. The War Game Model Loop.

War games can be further classified as manual, computer assisted, computerized and completely simulated. In the manual game, the opposing forces and a control group are human players who make all the decisions and assessments in accordance with predetermined rules, usually contained in a control pamphlet. The manual game can be modified by having only one side represented by players, with the control group playing the opposing side, in addition to controlling the game.

The computer-assisted game is similar to the manual game except that some portions, such as maintaining logistical status and casualty and damage assessments are done by digital computer. A computerized war game is a simulation which must be interrupted at times to allow human players to inject the decisions and judgments required. A completely simulated game proceeds to its conclusion without interruption, all necessary decision making having been incorporated in the computer routine. These war game classifications just defined are those of the U. S. Army Strategy and Tactics Analysis Group at Bethesda, Maryland (13). They generally conform to the classifications of most gamesters such as Olaf Helmer (20), M. G. Weiner (37), R. W. Shephard (34) and others.

Manual games are the stepping stones to computerized games and simulations; as such they merit a brief discussion. Two games of contemporary origin will be described as to their methods and purposes.

The Strategic War Planner (SWAP) was developed by the Rand Corporation's Helmer and Shapley in 1959 (20). Its purpose was to simulate two phases of a strategic air war. Phase I consisted of a five year procurement phase beginning with present force composition. In the five annual moves, prior to hostilities, both red and blue forces select weapons systems, early warning systems, logistical support capabilities, bases by quantity and location, research and development activities, doctrinal policies and other major parameters of strategic planning within overall annual budget constraints. Considerable flexibility is afforded each force planner by offering a wide variety of feasible choices. Each choice is represented by a simple mathematical model which denotes the cost of the choice. For example, tanker aircraft might be represented by 100 + 10/Y. This model is fictitious, but of the type used. In the example, a squadron of 15 tanker aircraft of specified capability is obtained for an initial cost of 100 at an annual operating cost of 10. Phase II is the operational phase and is concerned with the first few days of a strategic air war. It is played on a geographic game board superimposed with a hexagonal grid that affords reasonable simulation of flight paths and circular defensive capabilities. Play is time incremented on an hourly basis. At the end of each hour assessment is determined by the game's extensive rules on a probabilistic basis, and player decisions are allowed within the established rules. The game tests the effectiveness of the player's procurement and deployment decisions during Phase I and the major strategic decisions involved in planning and directing a strategic air strike during Phase II. Assessment is in terms of losses in aircraft, air bases, and missile launching sites, urban destruction, and mortalities.

In 1962 the British Army Operational Research Establishment (AORE) presented a tactical level war game at the Operational Research Society Conference (34). The AORE game was set up to study a tactical battle at Corps level in Northwestern Europe. It is a two-sided game with separate control. The elements which are represented during play of the game are infantry, armor, airborne forces, engineers, field artillery (conventional and nuclear), anti-aircraft, tactical air support and air reconnaissance. The game is played in three rooms, one for each of the opposing forces and one for the control element. In general, information flow is as reflected in Figure 2. The terrain model is a scale relief model of the area of interest 150 x 90 kilometers in size, which is divided into 2 km squares. Pieces

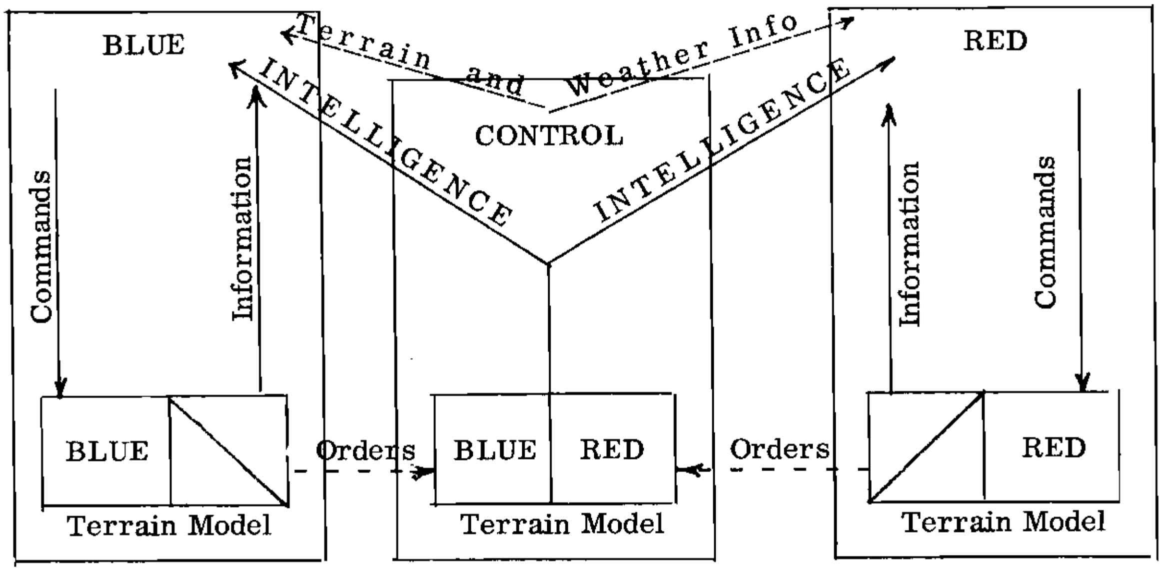

Figure 2. AORE Information Flow.

are used to represent units of company size, though both division and integration of the pieces is possible. One cycle of the game is representative of an hour of actual combat, during which each commander relays necessary tactical orders for subordinate units to the control staff. Control will then, in accordance with a very detailed set of rules, assess the interaction of opposing tactical plans and provide the tactical situation to both players for the subsequent cycle of the game. Some information is completely provided and some is not according with the game's rules. For example, information on one's own forces is generally fully known, whereas intelligence of the enemy forces is probabilistic in nature. Similarly, the rules which govern assessment of the situation are both deterministic and stochastic. The rate of tactical movements under most circumstances would be governed by a deterministic rule, whereas the number of casualties suffered in negotiating a minefield would be determined from a probabilistic rule. During play the participants are broken down as follows:

Control	Each Player Side
1 chief controller	1 commander
2 asst. controllers	1 chief of staff
5 assessors	1 intelligence officer
2 recorders	2 assistants

The game takes about six weeks to play with the accomplishment of two to three game cycles per day. Commanders of general officer rank are obtained from outside AORE, which serves two useful purposes; the games do not become stereotyped and tactical commanders become convinced of the validity of the results obtained.

War gaming, of course, should never be considered as an end in itself. It is merely one of several useful techniques in operational analysis which lends itself particularly well to competitive situations, especially those of a future time-frame. There are several significant limitations to hand-played games. It takes considerable time to set-up and play the game; input data is generally not complete, particularly in such areas as morale, leadership, fear and fatigue; complete realism concerning units on the flanks and strategic forces is not possible without making the game so cumbersome that it can not be played in a reasonable time; and the effects of learning during play are minimized, due to the lack of significant replication in play.

Digital Simulation -- A New Dimension in Problem Solving

The high-speed digital computer has given considerable impetus to war gaming through digital simulation. Its memory capacity and speed have certainly added to the potential scope and over-all value of gaming procedures. Military problems which involve many interrelated probabilities can be formulated as a digital simulation and replicated to a desired level of confidence. Of equal or greater importance, the model's parameters can be varied affording sensitivity analyses of their effects on model behavior, and then through further analysis, outside the computer, on the system behavior. There are, of course, disadvantages inherent in digital simulation. It is generally expensive. Even a small simulation requires an immense computer capacity and the model building and programming of human decision processes into computer language is difficult. The Signal Corps Ground Combat Simulator, to be discussed in Chapter II, required five years to program and debug into an operating simulation (3). At the present time considerable misunderstanding of computer simulations causes opposing and erroneous reactions by many professional military men (13, 35, 37). Some accept simulation results as an entirely valid prediction of how the problem will be ultimately solved, while others express a complete lack of confidence in the machine simulation of human decisions. What must be realized is that simulation techniques are intimately tied to model building, and it is the model that must be judged rather than the computer. The mathematical model of any simulation must include all the significant factors of the activity being studied and accurately reflect the real world relationship between them.

In the following chapter a number of computer simulations will be examined. Before proceeding, it should be worthwhile to reflect upon an admonition by Rand's E. S. Quade given in 1959 to a group of military and civilian decisionmakers associated with the Defense Department (35).

> The high-speed digital computer is sometimes equated with modern decisionmaking. There exists a belief that all that is needed to solve the most difficult problems is a bigger computing machine which is sure to come along. On the contrary, today a computer alone does not solve the problems of interest to military decisionmakers; all that it does is execute that series of instructions, laid out by some mathematician, that may lead to a solution. It is just a tool; it cannot do anything with problems it is not told to do. Solutions by computers are only as good and as sensible as the people who define the problem, state the objective, and choose the criterion can make them.

CHAPTER II

A LITERATURE SEARCH INTO THE DIGITAL SIMULATION OF MILITARY OPERATIONS

The Army Deployment Simulator

This program was recently written by the Rand Corporation for simulating the air deployment of army units from peacetime locations into an area of actual or potential combat (33). The program is written in Fortran IV and requires the following inputs to perform its simulation:

a. Location and capabilities of onload, enroute and offload bases

b. Location and composition of army units to be deployed

c. Location and composition of required prepositioned equipment

d. Location, characteristics, capabilities and number of available transport aircraft

e. Statement of deployment priorities

From this input data, the program:

a. Selects maximum flow routes by aircraft type to and from each onload base

b. Allocates aircraft to onload bases

c. Performs a detailed loading of each aircraft

d. Prepares a plot of the cumulative deliveries of personnel and cargo at the offload area during deployment

There are two phases to the program. The network phase accomplishes route selection. Thereafter, the loading phase allocates aircraft to bases and priority groups, loads the aircraft and completes the deployment. The program will be briefly described in terms of these phases.

The program accomplishes route selection through a network analysis of the system of onload, enroute and offload bases. The deployment bases constitute the nodes and the non-stop distances between every pair of bases constitute the branches of the network. As an entity the network is generally complex. A brief discussion of the data inputs required for the network phase best explains this complexity. Ferry ranges vary according to payload and individual type aircraft which in turn determine a number of branch denials. Base characteristics such as runway length and maintenance capabilities will constitute base denials to some type of aircraft. The base components of ground time, which are considered as part of appropriate branch lengths, will generally vary from base to base. Political considerations such as forbidden overflight will alter some branch lengths. With these inputs the computer routine executes a searching procedure to select feasible routes and from among these orders them from maximum to minimum flow. In the final step a payload-time out table for each combination of aircraft type and onload base is prepared specifying its maximum-flow route(s).*

The loading phase accomplishes aircraft allocation, loading and deployment through an algorithm based on inputs that spell out requirements by priority, locations of troops and vehicles, and the quantity and capabilities of available

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*More than one maximum flow route could possible exist due to varying payloads.

transport aircraft. The routine is quite straight-forward for the initial sorties, being easily determined by priorities and capabilities. Completion of the deployment is thereafter achieved by the application of several rules which in turn consider priorities for remaining requirements, aircraft type, eligible stock lists, branch flow capabilities and passed-over aircraft through a series of logic statements in the algorithm.

The program outputs include vehicle data, a distance table, a priority group composition listing, a priority group graph, an offload base activity listing and a listing of aircraft release times. The computer running time is relatively small. Deployments of a reinforced division from several locations over multiple routes have been simulated in less than ten minutes.

GPSS III and Simscript

Numerous military problems lend themselves to solution through the application of queuing theory. For examples, the determination of service troop and equipment requirements for the reception, discharge and clearance of supplies at a port facility (9), the troop and equipment requirements for a communications system (27), a variety of maintenance problems (5, 19) and even the analysis and determination of the number of supporting weapons systems (particularly those of considerable expense) required to meet requests for fire support can be formulated as queuing problems. IBM's General Purpose Systems Simulator III (21, 22) and the Rand Corporation's Simscript (17, 18, 24) provide special purpose programs ideally suited for such simulations.

The programming of simulation models in the general-purpose languages such as Fortran and Algol has proven to be an expensive and time-consuming task that has required the concerted effort of expert programmers (18, 24, 26). If the problem being studied is of sufficient importance the expense may be relatively unimportant, but the time required to accomplish programming may well be unacceptable. It is these considerations that have led to the development of numerous special-purpose simulators. In general, special-purpose languages allow the simulation model to be described in "real world language" by shifting a great deal of the translation task to the computer. The degree to which this translation shift takes place does, of course, vary with each special purpose program. The result is more powerful languages which require less complicated flow diagrams, fewer instructions to the computer, much less programming skill by the programmer, and a considerable increase in computer running time for comparative models. GPSS III and Simscript are programs of this type. They are intended for similar type simulations, but are somewhat different in their structure.

GPSS III is a higher level language than Simscript, in that it shifts a good deal more of the translation task to the computer. Consequently, formulation of the flow diagram and the writing of the program in terms of the program's eleven entities (21) and their respective attributes is a relatively easy task. The programmer must simply understand the functions of a set of flow-chart symbols and the rules for combining them. Once the flow diagram is completed, the program is easily written (18, 21, 22).

Though Simscript is more powerful than Fortran (one Simscript command equals four to five Fortran commands) (18), it requires greater programming skill than does GPSS III. The system being simulated is modeled in terms of any number of entities, classified as permanent or temporary, which the programmer must define along with the types of operations to be performed (17, 18, 24). Simscript, then, is a language similar to Fortran, but more powerful in use due to its special-purpose design. In February 1966, the Rand Corporation published its first memorandum on Simscript II (24). Numerous conceptual changes were made. Simscript II is not translated through Fortran, but compiles directly to the machine, and therefore contains all the elements of an algebraic compiler. The language is structured in seven levels affording considerable flexibility in its application. Level I consists of only eleven statements and has the intended purpose of easily teaching programming concepts to the novice programmer, while level VII provides for adding commands to Simscript II so that the experienced programmer is able to create problem oriented applications to the basic language (24). For instance, the programmer could add an analysis of variance sub-routine that could be applied to particular data resulting from the simulation run (17, 24).

A succinct comparison of GPSS and Simscript has been made by Ginsberg (18).

> If it is possible to write the program in GPSS, if memory limitations will not be exceeded, if the larger running time is not "excessive" then GPSS should be used. Otherwise Simscript or one of the other languages should be used.

Militran

Under the sponsorship of the Naval Analysis Group of the Office of Naval

Research, the Militran System was developed by the Systems Research Group, Incorporated and became operational in mid-1963 (26). Like Simscript II and GPSS III it is a computer language with its own compiler. The underlying philosophy of Militran is that the descriptive and technical aspects of a military conflict situation can be expressed in terms of generic elements, whose interactions may be categorized by a set of generic relationships. The job of the model builder then becomes one of determining the model structure that truly simulates the situation under study, through the use of these generic elements and the assignment of parameter values. Levine states that the three essential steps to computer simulation are model formulation, computer programming, and experimental evaluation, and that it is the first and third steps which are clearly decisive to the validity of an analysis through computer simulation (26).

Examples of the generic elements in Militran are platforms, weapons, passive targets, linkages, sensors (detectors, trackers or directors), launchers and supply centers. Two examples of the many generic relationships are as follows:

a. Platforms* may attack other platforms, passive targets, linkages, sensors, launchers and supply centers

b. A linkage may control and transport platforms, detectors and other linkages.

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*The basic vehicle in a target destruction process. It is the center of association for the weapon as well as the sensors that locate a target and direct the weapon (26).

In structure, Militran is a hierarchy of sublanguages. The first is the Militran Core which is a fixed format, highly military-oriented language that provides for the simulation of a wide variety of doctrines and events which commonly occur. So, for many simulations this provides a means of rapidly obtaining an operative program. For simulations of a more complex or non-standard nature the Event-Processing language is used for increasing the scope of the Militran Core. Programming in this second-level seems to closely resemble that type of simulation programming encountered with Fortran and Algol. Finally, of course, there is the machine oriented language which the expert and experienced programmer may use for adding sub-routines or for the modification of Militran itself.

Militran has a number of appealing features. The language is not machine oriented, though presently binary decks exist only for the IBM 7090/94. Precoding need not be done by a programmer and the programming required by the Militran Core is relatively easy and time-saving. A program that would require a year or so to write in a general purpose language can be written and operating in a few weeks (26). Lastly, its military oriented core serves to greatly facilitate communication between the model builder and the programmer.

Ground Combat Simulator

The Signal Corps Ground Combat Simulator is an immensely complex and comprehensive simulation of combat operations at the division level. It was developed by the General Analysis Corporation over a six year period -- 1957-1963

(3). A year was taken for the feasibility study and five years to develop the program for the IBM 709. The program has since been rewritten for the IBM 7090/94 (3). Though the simulator's purpose was to allow the detailed study of communications within a division under many tactical situations, an extremely detailed time-sequences ground combat simulation has been developed with the obvious capability of wider applications.

In all, the program consists of fifty sub-models which will not be discussed in detail within the contents of the literature survey. The approach will be to generally discuss seven categorizations of these sub-models. It should be deservedly stated that anyone interested in the digital simulation of military operations would profit greatly from the detailed study of the Ground Combat Simulator. The benefit is not in the programming techniques used, but rather in the methodology of model formulation.

Terrain is described with a single sub-model TERRTP which finds the type terrain all units are presently occupying (according to one of four classifications) and stores the appropriate terrain type with each unit index. Movement is described with seven interrelated sub-models which represent orders to move, location in the battle area, route selection, state of present engagement and attrition, rates and directions of moves, and termination of moves. For example, one sub-model GOPOUT decommits units of the general outpost when they are driven into the forward edge of the battle area. Fire is described with eight sub-models which determine opposing units in contact, coordination of fires, fire requests, target intelligence, target selection, fire control, volume of fire and effects of fire. For instance, TARGET selects artillery targets of opportunity and upon receipt of fire requests, allocates direct support batteries for target engagement. Attrition is determined by a cross-section of sub-models in several categorizations. CARDAM, for example, computes the attrition and suppressive effects of artillery fire and adjusts all effected listings accordingly. Intelligence acquisition, dissemination and interpretation is handled by five sub-models. One of these, FARSAW, transmits intelligence accumulated by long range surveillance units. Seven sub-models represent command and control such as BNDEC which sends status reports from battalion headquarters to brigade headquarters and commits and decommits companies according to a variety of logic statements. The seventh categorization of sub-models deals with the communications aspects of the simulation. In broad sub-categories they deal with message generation, communication system condition and communications traffic. These sub-models are intimately tied to the tactical situation and involve a variety of simulation techniques such as random generation, queuing, information-feed back and searching.

The most significant disadvantage to GCS is that it is a fully computerized simulation which limits the flexibility of the command and control portions of the model.

Carmonette

Carmonette is an event-sequenced digital simulation of two-sided company sized ground combat (39). It was developed for the purpose of evaluating specific competitive weapons' systems for the U. S. Army. The model is therefore aggregated at a low level. For example, Carmonette considers individual tanks and infantry squads in performing its simulation. The characteristics of these entities are described in sufficient detail so that varying inputs to the simulation can be measured and evaluated experimentally.

Of particular interest is the scheme by which this model considers the effects of terrain upon such vital aspects as movement, observation, effectiveness of fire, acquisition of intelligence and communication (39). The area of terrain interest is divided into 1296 terrain compartments, each of which is representative of a square of terrain 100 by 100 meters in size. Indexed for each terrain compartment are values which describe the characteristics of the terrain square. These are elevation, height of vegetation or surface irregularities, concealment from enemy ground observation, cover from enemy fire, trafficability, and man-made features. The model's methodology regards these characteristics as "non-directional" features. When coupled with directional features such as unit missions, terrain objectives, target priorities, moving and firing doctrines, terrain obstacles, and existing road nets the computer routine is able to simulate conduct of the battle. At each decision point, in the event-sequencing, the movement and firing actions of each entity can be described in a probabilistic sense. From these probabilities the action of each entity is then determined by application of the Monte Carlo technique (39). Assessment of each action then occurs in a similar fashion.

Obviously Carmonette is a detailed and complex simulation that required a considerable effort to model and program. However, its level of aggregation and stochastic nature are very appealing features when consideration is given to the purpose for which it was designed. If the operational characteristics of a conceptual weapons system can be adequately described, much useful information for the design of such a weapon system can be gained through the use of conventional experimental techniques. One further advantage is apparent. Later field experimentation can be guided by the results of the computer experiments, with an accompanying savings in time and money.

Centaur and Legion

Centaur is quite similar to GCS in its formulation and structure with one vital and important exception. It is a man-computer simulation of ground combat at the division level, developed by the U. S. Army Strategy and Tactics Analysis Group at Bethesda, Maryland (13, 36). It is perhaps the most complex and comprehensive military simulation ever attempted.

Centaur is a two-sided division level simulation designed to test war plans and to conduct military operations research. Its primary units are infantry and tank companies, armored cavalry troops and artillery battalions. Decisions relating to them such as casualty rates and resupply are made prior to the game and incorporated into the computer routine. Units above these primary elements are represented by human players; tactical decisions are made during play and communicated to the simulated units by means of input orders. Included in the computer routine are sub-models of the parameters which will have a significant effect on each combat element. These are:

Terrain and Weather
Movement
Surveillance
Message
Firepower
Assessment
Supply
Replacement

From systems charts an executive program is prepared; information is converted into mathematical models and these are coded for computer operations. Assumptions and factors such as the mission, task organization, deployments, supply status, equipment characteristics, terrain, weather and relative intelligence status are entered as input. The simulation is on a time interval basis. Every fifteen minutes the situation is examined to see if human decision is required by either of the opposing sides. During these periods the effects of fire and movement are assessed every five minutes. The game is played in a two-story control room on rather sophisticated display equipment. There are two display screens on which information can be projected in a variety of configurations. Additionally, the machine can be questioned. For example, it could be asked: What will the fallout pattern be at six hour intervals for the next twenty-four hours if I detonate a 5KT weapon at NA0491? The computer, having been programmed with weapons effects and wind conditions will make the computations and in a few seconds the fallout patterns will be projected on one of the screens.

Numerous validations of Centaur have been made in varying ways. Military personnel with considerable combat experience have reviewed and criticized the game; some games have been rerun manually to test the logic, accuracy, completeness and sequence of operations; finally games have been rerun with situation and data changes to gain sensitivity analyses of parameters.

Centaur has some shortcomings in that the aspects of tactical air operations, army air operations, air defense, personnel replacement, and maintenance, medical and transportation support are not simulated in the program. All of these vital aspects are to be included in Legion, now being developed as Centaur's successor (13, 30).

Dynamo

Dynamo is a computer language with its own special purpose compiler written by Dr. Phyliss Fox (Mrs. George Sternlieb) and Alexander L. Pugh of the Massachusetts Institute of Technology (32). A Dynamo model consists of a set of zero and first order difference equations, which describe the behavior of dynamic feedback systems which so frequently occur in business, economics and engineering. Its intended use is in building simulation models of industrial systems as described by Dr. Jay W. Forrester in his book, Industrial Dynamics (16).

A Dynamo model is written in terms of three principal types of variables categorized as levels, rates and auxiliaries (32). A level is a quantity whose value at any time is a function of its value at the preceding time (in accordance with a set time increment) and on the value of other variables during the set time increment. Rates represent decisions which are based on information feedback and thus on the state of the system at the present time, or some previous time when information time delays are represented in the model. Such decisions are implemented in the succeeding time increment or at some later time, again dependent on the presence or absence of delays in the model. Auxiliaries are variables which simplify the algebraic structure of equations describing rates. In a Dynamo flow diagram all auxiliaries ultimately feed into some particular rate(s).* Variables providing information feedback and those specifying the time-length of a delay are examples of auxiliary variables.

Of special interest is the system of time notation utilized by Dynamo. Though the model is written as a set of difference equations, the notation used is not the conventional notation. Looking at the following level equation,

$$\text{LEV.K} = \text{LEV.J} + (\text{DT})\,(\text{IN.JK} - \text{OUT.JK})$$

we can see that the level at time K is equal to the level at time J plus delta time (the time increment) times the algebraic difference between input and output rates during the interval JK. This time notation is reflected graphically in Figure 3 (32).

Though designed for the simulation of industrial systems, Dynamo is ideally suited to the study of any continuous system (or one which can be reasonably taken as continuous) where information feedback is a significant factor in the system's behavior. It is helpful to recall Forrester's definition of an information feedback system (16) -- "An information-feedback system exists whenever the environment leads to a decision that results in action which affects the environment."

- - - - - - -

*It is possible for an auxiliary variable to feed into more than one rate.

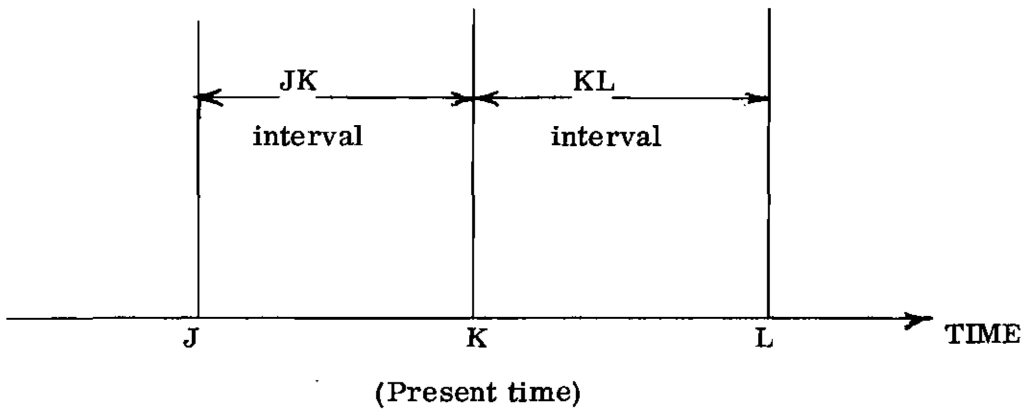

Figure 3. Dynamic Time Notation

A multitude of military problems fall easily within the bounds of this definition. In October 1966, Dr. Joseph Krol of the Georgia Institute of Technology presented a paper at the Thirtieth National Meeting of ORSA (Operations Research Society of America) on Military Applications of Industrial Dynamics (25). Experimental military simulations in Dynamo have been accomplished by graduate students at Georgia Institute of Technology modeling a rifle platoon in the defense (1), the Lanchester equations of warfare (8), Phases I and II of an insurgency (15) and the transportation system of a communications zone. Dr. Krol concludes (25):

> The most difficult aspect of industrial dynamics (and of any other computer simulation technique) is the ability to identify a system under study in terms of its significant variables and the relationships between these variables. However, experience shows that any mature officer can become an expert in applying industrial dynamics to a wide range of military problems.

Conclusions

Digital simulation programs for military operations are numerous and offer a wide variety, both in scope and approach. Some are built from general-purpose languages while others are true computer languages with their own specially oriented compilers. Some are fully computerized; some offer manual override; and still others are true man-machine simulations. Many other useful and valid military simulations exist in addition to those dealt with in this chapter: those discussed were hopefully selected as a representative cross-section of what is available.

Some general conclusions which can be drawn from this literature search are the following:

a. Model building is the vital step in any type of simulation. If the model does not consider all relevant and significant factors, and if their "real world" interrelationship is not adequately represented, then the analysis which follows the running of the program is rendered meaningless.

b. Analysis, outside the computer, is equally important. A valid simulation is of little value until it is correctly interpreted in terms of the real world problem under study.

c. Special-purpose programs are of great assistance to the analyst in enabling model formulation with greater ease and at a considerable savings in time. However, such programs should never be used as a crutch to analysis. To the contrary, the model builder must put forth the extra effort to be sure that he fully understands his own model, especially its shortcomings.

d. As a general rule, man-machine simulations or those providing manual override seem preferable, due to their greater flexibility, to fully computerized simulations. However, there are obvious exceptions. If fully playing the enemy and command flexibility are not overriding considerations to the problem at hand, a fully computerized model is probably preferable, due to its comparative ease of handling and lesser expense.

Digital simulation truly does provide a new dimension in military problem solving, though E. S. Quade's admonition of eight years ago must not be forgotten, "....it cannot do anything with problems it is not told to do...." (35).

CHAPTER III

THE TACTICAL PROBLEM

Negotiation of a Defile

The successful negotiation of a defile has been an often sought military maneuver since Hannibal successfully crossed the Alps in 218 B. C. However, it is most often a very perplexing problem, particularly on the modern battlefield. Publius Scipio did not possess the needed surveillance, movement and firepower capabilities to challenge Hannibal's forces when they were concentrated in the Little Saint Bernard Pass, and most vulnerable to attack by the Romans. On today's battlefields no commander can expect to be as fortunate as Hannibal. The enemy will most likely be aware of our dispositions because modern technology has provided surveillance and reconnaissance means that can not be fully countered. These means coupled with modern weaponry defy any commander to needlessly concentrate his forces. To do so is to invite destruction by the enemy.

The Assault River Crossing

The assault crossing of an unfordable river, especially by armored and mechanized forces faced by a well trained and modernly equipped enemy, presents the classic military problem of defile negotiation. Surely the enemy will cover his withdrawal with all available means; his armored cavalry, artillery (conventional and nuclear), tactical air and combat engineers will all play their role in covering the withdrawal, so that the enemy can successfully place the river obstacle to his front, destroying the existing bridges as he completes withdrawal across the river. We can expect that he will either defend or strongly outpost the river line. The task is to maintain the momentum of our attack, not giving the enemy time to prepare his defenses. But, to do this, we must cross an unfordable river with the means at our disposal. In the mechanized infantry division, as it exists today, this requires the use of tactical bridging (bridges and powered rafts) at suitable crossing sites within the division zone of attack. In effect, each of these crossing sites will constitute a defile through which elements of the division must be funneled in order to continue the attack. Fortunately, modern technology partially alleviates this problem and provides a basis for our existing river crossing doctrine. The assault infantry can swim the river in their armored personnel carriers or can conduct an air assault against the enemy in tactical helicopters, and of course the infantry can assault the enemy through some combination of these two means. Thus, to a certain extent the division can remain deployed with elements of it avoiding the defiles. The U. S. Army has also developed amphibious self-propelled artillery pieces and light tanks. However, this equipment is not generally in the hands of troops and most of the artillery and the tanks of our divisions today must therefore cross the river on tactical bridging.

The Mechanized Infantry Division

The reinforced mechanized infantry division with which this research is concerned consists of seven mechanized infantry battalions, three tank batallions, two armored cavalry squadrons, nine field artillery battalions, two anti-aircraft artillery battalions, four combat engineer battalions, two engineer float bridge companies and the normal organic and attached supporting units (4). The total number of non-amphibious vehicles in the division is 4,498 of which 1,109 are greater than class 12 (tons) in weight. The organic division engineers have the tactical bridging equipment as listed in Table 1.

Table 1. Division Crossing Equipment

Equipment	Quantity
Light Tactical Rafts (Class 12)	14
Mobile Assault Bridge (Class 60)	1
or	
Mobile Assault Rafts (Class 60)	4

The two attached engineer float bridge companies have the tactical bridging equipment shown in Table 2.

Table 2. Attached Crossing Equipment

Equipment	Quantity
M4T6 Rafts (Class 55)	20
or	
M4T6 Rafts	14
M4T6 Bridge (Class 55)	1
or	
M4T6 Rafts	8
M4T6 Bridges	2
or	
M4T6 Rafts	2
M4T6 Bridges	3

It can readily be seen that a number of possible choices exists in the manner of utilizing this bridging equipment. The equipment's capabilities and the basis for the foregoing combinations of equipment will be presented during the discussion of crossing plans.

River Crossing Doctrine

The general tactical situation presented in the previous discussion of the assault river crossing calls for what is termed a hasty river crossing, which provides for rapid movement through the crossing areas (see Figure 4), rapid deployment on the far side, and early commitment of an exploiting force. The approach to the river is normally made on a broad front after rupture of the enemy's defenses and every attempt is made to catch the enemy astride the river and to capture existing bridges intact (10). However, our enemy is likely to be

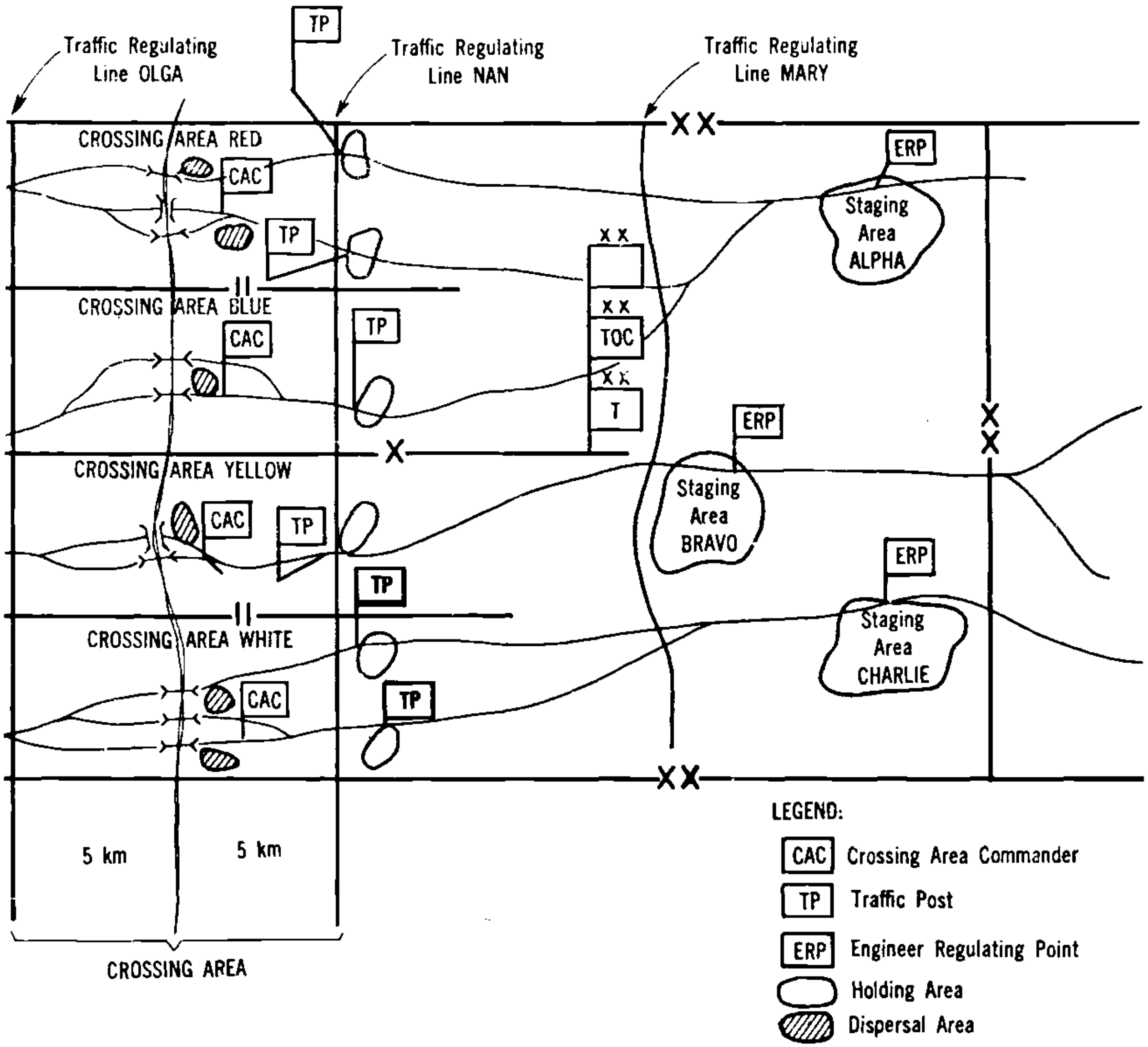

Figure 4. Schematic Division Zone of Attack.

a skillful adversary and our efforts to destroy him on the near side of the river and to capture bridges intact may not be rewarding. If not, the momentum of our attack, as mentioned before, must not be lost. The infantry will mount an over-water and/or airmobile assault to rapidly seize a bridgehead sufficient to protect the river from enemy small arms fire, so that raft and bridge construction may commence. When sufficient tanks, artillery and other needed support units have joined with the infantry, break-out from the bridgehead occurs, and the attack against the enemy is continued with full force.

Crossing Plans and Defile Control

Here is the crux of the matter, and as a basis for the Dynamo modeling a particular river crossing problem presented at the U. S. Army Command and General Staff College during the academic year 1964-65, will be used (4). A part of the concept of operation as extracted from the division operations plan is as follows:

EXECUTION

a. Concept of Operation.

(1) General. This is a hasty river crossing that will be conducted in two phases. Brigades may be committed individually to maintain the momentum of the attack. Initial crossings will be made by amphibious vehicles and armored carriers in conjunction with airmobile forces. Maximum advantage of darkness will be taken to conceal movements and to reduce effectiveness of enemy fires.

(a) Phase I (K-1 hour to K+8 hours):

1. K-1 to K-hour. Air and artillery preparation on call.

2. K-hour to K+2 hours. Seizure of crossing areas, amphibious assault of river line, initiation of raft construction, seizure of objectives 1 and 2 by airmobile forces.

3. K+2 hours to K+8 hours. Initiation of bridge construction, link-up between amphibious and airmobile forces, complete securing of objectives that control line VICTORIA.

(b) Phase II (K+8 hours to K+16 hours). Secure objectives that control line ELIZABETH by ground and airmobile forces.

(2) Maneuver.

(a) Phase I. 1st Bde using 1st sqdn, 23d Cav, covers north flank and blocks enemy escape routes. 1st Bde and 3d Bde move rapidly to river, secure crossing areas, seize objectives that control line VICTORIA by ground and airmobile assault, and secure line VICTORIA.

(b) Phase II. 1st Bde and 3d Bde continue, on division order, to attack to the east. 1st Bde and 3d Bde seize objectives 3 and 4 respectively by ground and airmobile forces and assault and secure corps bridgehead (line ELIZABETH). 1st Sqdn, 23d Cav, blocks SEWEWEEKSPOORT Pass.

From this concept of operation and the tactical bridging equipment available the following crossing capabilities become apparent.

Table 3. Equipment Crossing Capabilities*

Equipment	Class	Construction Commences	Operation Commences	Crossing* Capability (vehicles/hr.)
Light Tactical Raft	12	none required	K + 1	6
Mobile Assault Raft	60	K + 1	K + 1.5	12
M4T6 Raft	55	K + 1	K + 2.5	6
M4T6 Bridge	55	K + 2.5	K + 6.5	400
Mobile Assault Bridge	60	K + 2.5**	K + 4	400

- - - - - - -

*Based on equipment capability, river current speed and river width.

**Construction could commence at K + 1, but as will be seen in the following discussion this can be rejected as an unacceptable alternative.

The manner in which to utilize the division's available tactical bridging must be decided by the sound evaluation of conflicting requirements.

a. The crossing of tanks and supporting artillery must commence at the earliest possible time to reinforce the assault infantry.

b. The tanks, direct support artillery and needed logistical support vehicles of the assault brigades must be across the river by K + 6 hours, in order to completely secure line VICTORIA by K + 8 hours. This will amount to 260 vehicles greater than class 12.*

c. The crossing of the entire division should be accomplished in the shortest possible time and certainly should not exceed 14 hours. A longer crossing time would stretch the division beyond the capability to support itself logistically, particularly when astride a major obstacle.

Obviously the latter requirement conflicts with the first two. The maximum number of vehicles can be crossed at K + 6 hours by sole dependence on rafting, whereas the entire division could be crossed in the least overall time by the maximum use of tactical bridges. Five crossing plans will be examined to see which one best meets these conflicting requirements. Briefly, these crossing plans are shown in Table 4 which follows. Plan E envisions rafting with the mobile assault rafts during the early critical phase of the crossing, and thereafter swimming the mobile assault rafts together at a suitable site and making them into a mobile assault bridge.

- - - - - - -

*The number of such vehicles in the two assault brigades.

Table 4. Division Crossing Plans

Plan	Light Tactical Rafts	Mobile Assault Rafts	M4T6 Rafts	M4T6 Bridges	Mobile Assault Bridges
A	14	4	20	0	0
B	14	4	14	1	0
C	14	4	8	2	0
D	14	4	2	3	0
E	14	4 until K + 2.5 0 thereafter	14	1	0 until K + 4 1 thereafter

Coincident with the implementation of any of these crossing plans is the problem of defile control. A rpaid crossing will insure maintaining the momentum of the attack. Therefore, no matter which crossing plan is ultimately selected, an equally important consideration is that the crossing means available be used to their full capacity. In other words, downtime of crossings means due to a non-availability of vehicles at a crossing site can not be tolerated. However, a significant conflict of purposes exist; in achieving full utilization of the crossing capacity the density of units and vehicles must not reach such a concentrated level that it invites attack by fire (conventional or nuclear), which would result in the destruction of a significant portion of the division, such as an entire battalion. Therefore, the objective of the division's defile control measures is to maintain a smooth flow across the river at full crossing capacity, while not presenting the enemy a worthwhile target, due to needless congestion within crossing areas and defiles. Current doctrine provides for defile control through a system of staging areas, holding areas, dispersal areas and crossing area command posts. The staging areas and engineer regulating points do not directly affect the division. Their purpose is to control traffic of Corps and Army units which are moving forward into the division zone. Control within the division is exercised by ordering units into the holding areas based on the present crossing capability and the division's tactical plan. Units are formed into raft sized packets in the holding areas and held there until ordered to the crossing sites by the crossing area commanders in each battalion zone, again according to the crossing capability and the tactical plan. (See Figure 4, page 35.) Dispersal areas are provided within each crossing area for temporary halting and dispersal of units moving to the crossing sites due to disrupted traffic or reduced crossing means. Ideally, these dispersal areas should receive no use. Unfortunately, in actual practice they are frequently utilized.

The second problem, to which the Dynamo models will be addressed, is that of defile control. Significant questions will arise. How many vehicles, if any, should be within the defile and in the holding areas? When, and at what rate, should units move from a deployed position into the holding areas? To waht extent can significant changes in crossing capability be predicted? How many class 12 vehicles should be crossing on class 60 means at any one time? How will the division react to the loss of significant crossing capability? And most of all, is our present defile control doctrine the most effective that can be devised? If not, what changes for improvement should be made?

CHAPTER IV

THE DYNAMO MODELS

The Development of Successive Models

Six models were used in the conduct of this study. Model I was purely deterministic in structure. It allowed a comparison of crossing plans under ideal circumstances where traffic disruption, crossing means down time and defile control were not factors of significant importance. Some provision for these factors was made by including the information and decisions necessary to control the forward movement of units as inputs to the computer routine. Models II, III and IV were developmental models directed toward a simulation program that would provide the means to examine realistically the major factors associated with defile control. Model II included the addition of several probabilistic features. Delays, movement times and crossing capabilities were described in terms of theoretical distribution functions. More variability was added in Model III where movement times were described by several distribution functions with differing mean values. Model IV differed from its predecessors with the addition of a construction portion. This change provided for simulating the construction of rafts and bridges through application of the Monte Carlo technique, as opposed to simply providing this information as input data. With the development of Model IV only the addition of a crossing means predictive portion would be required to examine the decisions associated with controlling the forward movement of units. This predictive portion was added in Model V, which was used to investigate the area of effective defile control. Model VI allowed study of the effects of the unpredicted outages of crossing means upon defile control measures. Reliability factors for each type crossing equipment were used in conjunction with equipment repair rate distribution functions to simulate these unpredicted outages in a random manner.

In summary, Model I addressed itself to the comparison of crossing plans. Model II, III and IV were the stepping stones to Models V and VI, which were concerned with the study of defile control measures. Listings of Models I, V, and VI are provided in Figures 5, 6 and 7 respectively. A set of comprehensive flow diagrams are provided in the appendix. Listings of all models are available in the unpublished annex to this thesis.

Crossing Capability

Crossing capability is easily determined from the considerations of equipment capability, river current speed and river width (4, 10, 11). In Model I the equations were deterministic, which assumes no unplanned changes or fluctuations will occur. The equipment in operation is determined by three type equations. Taking examples from plans A, B and E respectively we have:

```
C      BRIO = 0                                      Bridges in Operation (Plan A)

45A    BRIO.K = STEP (1, 6.5)                        Bridges in Operation (Plan B)

59A    BRIO.K = TABLE (TBL1, CLOK.K, 0, 16,0.5) Bridges in Operation (Plan E)

C      TBL1* = 0/0/0/0/0/0/0/0/1/1/1/1/1/2/2/2/2/2/2/2/2/2/2/2/2/2/2/
X1             2/2/2
```

```
     ASSALLT RIVER CRCSSING,IE7CC. REED E DAVIS, CR JCSEFH KRCL
     MCDEL I FLAN C
     THIRTY MINLTE FREDICTIVE CAPABILITY
     EXFCNENTIAL CELAY 15 MIN LEVEL IN DEFILE
1L   CLCK.K=CLCK.J+(CT)(1+0)                  (    PRCBLEM TIME
6N   CLCK=0                                   (    INITIAL CCNCITION
45A  ERID.K=STEF(3,6.5)                       (    ERICGES IN CFERATICN
45A  MARC.K=STEP(4,1.5)                       (    MCBILE ASSALLT RAFTS IN OPN
45A  RFTC.K=STEF(2,2.5)                       (    M4T6 RAFTS IN CPERATICN
45A  LTRC.K=STEF(14,1)                        (    LIGHT TACTICAL RAFTS IN CFN
17A  MSCR.K=(400)(1)(ERIC.K)+(12)(1)(MARC.K)+(6)(1)(RFTC.K)   (  MAX CL 60 RATE
12A  MTCR.K=(6)(LTRC.K)                       (    MIN CL TWELVE CRCSSING RATE
40A  TCC.K=MSCR.K+(1/2)(MTCR.K+1)             (    TCTAL CRCSSING CAPABILITY EE
22A  TCS.K=(1/TCC.K)((MSCR.K)(CTIC.K)+(MTCR.K)(-CSIC.K)) ( TWELVE SIXTY AUX
56A  TCAS.K=MAX(TCS.K,C)                      (    TWELVE SIXTY AUX 2
12A  MTCS.K=(C.93)(MSCR.K)                    (    MAX ALLCWEC TWELVE XING SIXTY C
54A  TCCS.K=MIN(TCAS.K,MTCS.K)                (    CL 12 CRCSSING CN CL 60 MEANS
14A  ASCC.K=MSCR.K+(TCDS.K)(-0.95)            ( C  CLASS SIXTY CROSSING CAPABILITY
7A   ATCA.K=MTCR.K+TCCS.K                     (    CLASS TWELVE CC AUX 1
14A  ATCB.K=MTCR.K+(1.05)(MSCR.K)             (    CLASS TWELVE CC AUX 2 D
51A  ATCC.K=CLIP(ATCB.K,ATCA.K,CSSC.K,11C0)   ( CL TWELVE CRCSSING CAPAEILITY
12A  SVEH.K=(20)(CSIC.K)                      (    CLASS SIXTY VEHICLES AVAILAKLE
12A  TVEH.K=(20)(CTID.K)                      (    CLASS TWELVE VEHICLES AVAILAELE
54R  ASCR.KL=MIN(ASCC.K,SVEH.K)               (    ACTUAL CLASS SIXTY XING RATE
6N   ASCR=0                                   (    INITIAL CCNCITICN
54R  ATCR.KL=MIN(ATCC.K,TVEH.K)               (    ACTLAL CLASS TWELVE XING RA25
6N   ATCR=0                                   (    INITIAL CCNDITICN
1L   CSIC.K=CSIC.J+(CT)(SHDR.JK-ASCR.JK)      (    CL SIXTY VEHICLES IN DEFILE
6N   CSID=0                                   (    INITIAL CCNCITION
1L   CTIC.K=CTIC.J+(DT)(THCR.JK-ATCR.JK)      (    CL TWELVE VEHICLES IN CEFILE
6N   CTIC=C                                   (    INITIAL CCNCITICN
54A  SCR.K=MIN(ASCC.K,SVEH.K)                 (    SIXTY XING RATE AUX
26A  SCT.K=(ASCC.K-SCR.K+0)/(ASCC.K+1+0)      (    SIXTY DCWN TIME
59A  CSCP.K=TAELE(TEL4,CLCK.K,C,16,C.5)       (    CLASS SIXTY CRCSSING PLAN
C    TEL4*=0/C/0/0/1.4/C/C/0/0/0/0/C/44/0/0/0/0/0/0/C/C/C/0/0/C/C/0/0/0  (   D1
X1   /0/0/0/0                                                              (   C1
43A  SMFT.K=SAMPLE(CSCP.K,C.5)                (    SIXTY MEANS FRECICTEC TIME
56A  SMCT.K=MAX(SDT.K,SMPT.K)                 (    SIXTY MEANS DCWN TIME AUX
54A  TCR.K=MIN(ATCC.K,TVEH.K)                 (    TWELVE XING RATE AUX
26A  TCT.K=(ATCC.K-TCR.K+0)/(ATCC.K+1+0)      (    TWELVE DCWN TIME
7A   TVID.K=CSIC.K+CTIC.K                     (    TOTAL VEHICLES IN DEFILE
50A  CSDC.K=(9.2)(CSIC.K)/(ASCC.K+1)          (    CLASS SIXTY CEFILE CCNTRCL
54A  CSCB.K=MIN(CSDC.K,87)                    )    CL SIXTY DEFILE C AUX
26A  SCEL.K=(C.1)EXF(CSCE.K)                  )    CLASS SIXTY CELAY
20A  SHR.K=CSHA.K/SCEL.K                      (    SIXTY HA TC CEFILE AUX
51A  SCUM.K=CLIP(ASCC.K,SHR.K,CSSC.K,903)     (    SIXTY DUMMY
7A   SVAL.K=CSSC.K+CSIC.K                     (    SIXTY CROSSED PLUS CEFILE
51A  SHRA.K=CLIP(C,SCUM.K,SVAL.K,1109)        (    SIXTY HA TO DEFILE AUX 2
12A  SHAV.K=(20)(CSHA.K)                      (    SIXTY HA AVAILAELE
54R  SHDR.KL=MIN(SHRA.K,SHAV.K)               (    SIXTY HA TO DEFILE RATE
6N   SHCR=0                                   (    INITIAL CCNDITICN
47A  CTMS.K=RAMP(THCR.JK,0)                   (    CL TWELVE MCVEMENT STATUS
51A  DUM.K=CLIP(2.66,2.35,CTMS.K,1213)        (    DUMMY VARIAELE
51A  RTS.K=CLIP(4.85,DUM.K,CTMS.K,1938)       (    RATIC TWELVE TO SIXTY
54A  ASHR.K=MIN(SHRA.K,SHAV.K)                (    CL SIXTY HA RATE AUX
20A  TBR.K=CTHA.K/SCEL.K                      (    CLASS TWELVE HA RATE AUX 1
12A  TAR.K=(RTS.K)(ASHR.K)                    (    CLASS TWELVE HA RATE AUX 2
56A  THR.K=MAX(TBR.K,TAR.K)                   (    CLASS TWELVE HA RATE AUX 3
51A  TDUM.K=CLIP(ATCC.K,THR.K,CTSC.K,2841)    (    TWELVE DUMMY
7A   TVAL.K=CTSC.K+CTID.K                     (    TWELVE CRCSSEC PLUS CEFILE
51A  THRA.K=CLIP(0,TDUM.K,TVAL.K,3389)        (    CL TWELVE HA RATE AUX
12A  THAV.K=(20)(CTHA.K)                      (    TWELVE HA AVAILABLE
```

Figure 5.1. Listing of Model I.

```
54R   THDR.KL=MIN(THHA.K,THAV.K)                    (   TWELVE HA TO DEFILE RATE
6N    THDR=0                                        (   INITIAL CONDITION
1L    CSHA.K=CSHA.J+(DT)(SHAR.JK-SHDR.JK)           (   CL SIXTY VEHICLES IN H AREA
6N    CSHA=42                                       (   INITIAL CONDITION
1L    CTHA.K=CTHA.J+(DT)(THAR.JK-THDR.JK)           (   CLASS TWELVE VEHICLES IN HA
6N    CTHA=200                                      (   INITIAL CONDITION
7A    TVHA.K=CSHA.K+CTHA.K                          (   TOTAL VEH IN HOLDING AREAS
1L    CSMV.K=CSMV.J+(DT)(SDHR.JK-SHAR.JK)           (   CL SIXTY MOVEMENT LEVEL
6N    CSMV=0                                        (   INITIAL CONDITION
12A   SAVL.K=(20)(CSMV.K)                           (   CL SIXTY MVMT AVAILABLE
39R   CSMR.KL=DELAY3(SDHR.JK,0.70)                  (   CL SIXTY MOVEMENT RATE
6A    SOUT.K=CSMR.JK                                (   CL SIXTY HA ARR RATE AUX
51R   SHAR.KL=CLIP(SOUT.K,SAVL.K,CSD.K,50)          (   CL SIXTY HA ARRIVAL RATE
6N    SHAR=0                                        (   INITIAL CONDITION
1L    CTMV.K=CTMV.J+(DT)(TDHR.JK-THAR.JK)           (   CL TWELVE MOVEMENT LEVEL
6N    CTMV=0                                        (   INITIAL CONDITION
39R   CTMR.KL=DELAY3(TDHR.JK,0.70)                  (   CL TWELVE MOVEMENT RATE
12A   TAVL.K=(20)(CTMV.K)                           (   CL TWELVE MVMT AVAILABLE
6A    TOUT.K=CTMR.JK                                (   CL TWELVE HA ARR RATE AUX
51R   THAR.KL=CLIP(TOUT.K,TAVL.K,CTD.K,223)         (   CL TWELVE HA ARRIVAL RATE
6N    THAR=0                                        (   INITIAL CONDITION
18A   ASDH.K=(ASCC.K)(1+SMDT.K)                     (   CL SIXTY DEPLOYED TO HA AUX
51A   DUMY.K=CLIP(2.68,4.85,CTD.K,1351)             (   DUMMY VARIABLE
51A   RTTS.K=CLIP(2.35,DUMY.K,CTD.K,2076)           (   RATIO CL TWELVE TO CLASS SIXTY
12A   CSAV.K=(20)(CSD.K)                            (   SIXTY DEPLOYED TO HA AUX
54R   SDHR.KL=MIN(CSAV.K,ASDH.K)                    (   CL SIXTY DEPLOYED TO HA RATE
6N    SDHR=0                                        (   INITIAL CONDITION
54A   ASDR.K=MIN(CSAV.K,ASDH.K)                     (   CL SIXTY DEPLOYED HA RATE AUX
12A   AMR.K=(RTTS.K)(ASDR.K)                        (   ADJUSTED CL TWELVE MVMT RATE AU
56A   ATMR.K=MAX(ATCC.K,AMR.K)                      (   ADJUSTED CL TWELVE MVMT RATE
12A   CTAV.K=(20)(CTD.K)                            (   TWELVE DEPLOYED TO HA AUX
54A   TDHA.K=MIN(CTAV.K,ATMR.K)                     )   CL 12 DEP TO HA AUX
51R   TDHR.KL=CLIP(TDHA.K,0,CLCK.K,1.4)             (   CL TWELVE DEPLOYED TO HA RATE
6N    TDHR=0                                        (   INITIAL CONDITION
1L    CSD.K=CSD.J+(DT)(0-SDHR.JK)                   (   CLASS SIXTY VEHICLES DEPLOYED
6N    CSD=1067                                      (   INITIAL CONDITION
1L    CTD.K=CTD.J+(DT)(0-TDHR.JK)                   (   CLASS TWELVE VEHICLES DEPLOYED
6N    CTD=2189                                      (   INITIAL CONDITION
1L    CSSC.K=CSSC.J+(DT)(ASCR.JK+0)                 (   CL SIXTY VEH SUCCESS CROSSED
6N    CSSC=0                                        (   INITIAL CONDITION
1L    CTSC.K=CTSC.J+(DT)(ATCR.JK+0)                 (   CL TWELVE VEH SUCCESS CROSSED
6N    CTSC=0                                        (   INITIAL CONDITION
48S   RSHC.K=CSHA.K/(ASCC.K+1)                      (   SIXTY HA XING RATIO
48S   RTHC.K=CTHA.K/(ATCC.K+1)                      (   TWELVE HA XING RATIO
48S   RSDC.K=CSID.K/(ASCC.K+1)                      (   SIXTY DEFILE XING RATIO
48S   RTDC.K=CTID.K/(ATCC.K+1)                      (   TWELVE DEFILE XING RATIO
20S   RDC.K=TVID.K/TCC.K                            (   RATIO DEFILE TO CC
20S   RHC.K=TVHA.K/TCC.K                            (   RATIO HA TO CROSSING CAP
47A   DCL.K=RAMP(TVID.K,6.5)                        )   DEFILE CONC LEVEL
47A   DCLN.K=RAMP(1,6.5)                            )   DEFILE CONC LEVEL N
48S   ATVID.K=DCL.K/(DCLN.K+0.0001)                 )   CUM AVE VEH IN DEFILE
47A   HACL.K=RAMP(TVHA.K,6.5)                       )   HA CONC LEVEL
48S   ATVHA.K=HACL.K/(DCLN.K+0.0001)                )   CUM AVE VEH IN HA
47A   SDM.K=RAMP(SDT.K,0)                           )   SIXTY DOWN TIME LEVEL
47A   TDM.K=RAMP(TDT.K,0)                           )   TWELV DOWN TIME LEVEL
48S   ASDT.K=SDM.K/(CLOK.K+0.0001)                  )   CUM AVE 60 DOWN TIME
48S   ATDT.K=TDM.K/(CLOK.K+0.0001)                  )   CUM AVE 12 DOWN TIME
PRINT 1)SDT/2)TDT/3)TVID/4)TVHA/5)SHDR/6)THDR/7)SDHR/8)TDHR/9)SHAR
PRINT 1)RSHC/2)RTHC/3)RSDC/4)RTDC/5)CSSC/6)CTSC/7)CSD/8)CTD/9)CSMV
PRINT 1)RHC/2)RDC/3)CSHA/4)CTHA/5)ASCR/6)ATCR/7)TCOS/8)CTMV/9)THAR
PRINT 1)ATVID/2)ATVHA/3)ASDT/4)ATDT/5)CSMR/6)CTMR/7)SDEL/8)TCAS
PLOT  CSSC=S(0,1400)/CTSC=T(0,3900)/ASCR=R/ATCR=F/TVID=C
PLOT  SMPT=A/SDT=G/TDT=I/SDEL=D(0,10)/TVHA=H/CSID=J/CTID=K
SPEC  DT=0.05/LENGTH=16/PRTPER=0.10/PLTPER=0.10
```

Figure 5.2. Listing of Model I.

```
        ASSAULT RIVER CROSSING,TE700, REED F DAVIS, DR JOSEPH KROL
        MODEL V PLAN B
        PREDICTION BASED ON CONSTRUCTION STATUS
        CONSTRUCTION PORTION ADDED
        FIVE MINUTE LEVEL IN DEFILE
        SIXTY MINUTE PREDICTIVE CAPABILITY
1L      CLOK.K=CLOK.J+(DT)(1+0)                 (     PROBLEM TIME
6N      CLOK=0                                  (     INITIAL CONDITION
43A     BRIO.K=SAMPLE(BRIN.K,0.1)               (     BRIDGES IN OPERATION
7A      BRIN.K=BRIN1.K+BRIN2.K
51A     BRIN1.K=CLIP(1,0,BCS1.K,1)
C       BRIN2=0
47A     BCS1.K=RAMP(BCR1.K,2.5)
34A     BCR1.K=(1)NORMRN(0.25,0.05)
43A     MARO.K=SAMPLE(MRIN.K,0.1)               (     MOBILE ASSAULT RAFTS IN OPN
9A      MRIN.K=MRIN1.K+MRIN2.K+MRIN3.K+MRIN4.K
51A     MRIN1.K=CLIP(MAR1.K,0,MRCS1.K,1)
51A     MRIN2.K=CLIP(MAR2.K,0,MRCS2.K,1)
51A     MRIN3.K=CLIP(MAR3.K,0,MRCS3.K,1)
51A     MRIN4.K=CLIP(MAR4.K,0,MRCS4.K,1)
C       MAR1=1
C       MAR2=1
C       MAR3=1
C       MAR4=1
47A     MRCS1.K=RAMP(MRCR1.K,1)
47A     MRCS2.K=RAMP(MRCR2.K,1)
47A     MRCS3.K=RAMP(MRCR3.K,1)
47A     MRCS4.K=RAMP(MRCR4.K,1)
34A     MRCR1.K=(0.95)NORMRN(2,0.4)
34A     MRCR2.K=(0.98)NORMRN(2,0.4)
34A     MRCR3.K=(1.02)NORMRN(2,0.4)
34A     MRCR4.K=(1.05)NORMRN(2,0.4)
43A     RFTO.K=SAMPLE(RFIN.K,0.1)               (     M4T6 RAFTS IN OPERATION
7A      RFIN.K=RFIN1.K+RFIN2.K
10A     RFIN1.K=A.K+B.K+C.K+D.K+E.K+F.K
11A     RFIN2.K=G.K+H.K+I.K+J.K+K.K+L.K+M.K+N.K
51A     A.K=CLIP(1,0,AS.K,1)
51A     B.K=CLIP(1,0,BS.K,1)
51A     C.K=CLIP(1,0,CS.K,1)
51A     D.K=CLIP(1,0,DS.K,1)
51A     E.K=CLIP(1,0,ES.K,1)
51A     F.K=CLIP(1,0,FS.K,1)
51A     G.K=CLIP(1,0,GS.K,1)
51A     H.K=CLIP(1,0,HS.K,1)
51A     I.K=CLIP(1,0,IS.K,1)
51A     J.K=CLIP(1,0,JS.K,1)
51A     K.K=CLIP(1,0,KS.K,1)
51A     L.K=CLIP(1,0,LS.K,1)
51A     M.K=CLIP(1,0,MS.K,1)
51A     N.K=CLIP(1,0,NS.K,1)
47A     AS.K=RAMP(AR.K,1)
47A     BS.K=RAMP(BR.K,1)
47A     CS.K=RAMP(CR.K,1)
47A     DS.K=RAMP(DR.K,1)
47A     ES.K=RAMP(ER.K,1)
47A     FS.K=RAMP(FR.K,1)
47A     GS.K=RAMP(GR.K,1)
47A     HS.K=RAMP(HR.K,1)
47A     IS.K=RAMP(IR.K,1)
47A     JS.K=RAMP(JR.K,1)
47A     KS.K=RAMP(KR.K,1)
47A     LS.K=RAMP(LR.K,1)
47A     MS.K=RAMP(MR.K,1)
47A     NS.K=RAMP(NR.K,1)
34A     AR.K=(0.916)NORMRN(0.67,0.14)
34A     BR.K=(0.951)NORMRN(0.67,0.14)
34A     CR.K=(0.972)NORMRN(0.67,0.14)
34A     DR.K=(0.985)NORMRN(0.67,0.14)
34A     ER.K=(0.992)NORMRN(0.67,0.14)
34A     FR.K=(0.996)NORMRN(0.67,0.14)
34A     GR.K=(0.998)NORMRN(0.67,0.14)
34A     HR.K=(1.002)NORMRN(0.67,0.14)
34A     IR.K=(1.004)NORMRN(0.67,0.14)
34A     JR.K=(1.008)NORMRN(0.67,0.14)
34A     KR.K=(1.015)NORMRN(0.67,0.14)
34A     LR.K=(1.028)NORMRN(0.67,0.14)
34A     MR.K=(1.049)NORMRN(0.67,0.14)
34A     NR.K=(1.084)NORMRN(0.67,0.14)
43A     LTRO.K=SAMPLE(LRIN.K,0.1)               (     LIGHT TACTICAL RAFTS IN OPN
7A      LRIN.K=LRIN1.K+LRIN2.K
10A     LRIN1.K=AA.K+BB.K+O.K+P.K+Q.K+R.K
11A     LRIN2.K=S.K+T.K+U.K+V.K+W.K+X.K+Y.K+Z.K
51A     AA.K=CLIP(1,0,AAS.K,1)
51A     BB.K=CLIP(1,0,BBS.K,1)
51A     O.K=CLIP(1,0,OS.K,1)
51A     P.K=CLIP(1,0,PS.K,1)
```

Figure 6.1. Listing of Model V.

```
51A   Q.K=CLIP(1,0,QS.K,1)
51A   R.K=CLIP(1,0,RS.K,1)
51A   S.K=CLIP(1,0,SS.K,1)
51A   T.K=CLIP(1,0,TS.K,1)
51A   U.K=CLIP(1,0,US.K,1)
51A   V.K=CLIP(1,0,VS.K,1)
51A   W.K=CLIP(1,0,WS.K,1)
51A   X.K=CLIP(1,0,XS.K,1)
51A   Y.K=CLIP(1,0,YS.K,1)
51A   Z.K=CLIP(1,0,ZS.K,1)
47A   AAS.K=RAMP(AAR.K,0.75)
47A   BBS.K=RAMP(BBR.K,0.75)
47A   OS.K=RAMP(OR.K,0.75)
47A   PS.K=RAMP(PR.K,0.75)
47A   QS.K=RAMP(QR.K,0.75)
47A   RS.K=RAMP(RR.K,0.75)
47A   SS.K=RAMP(SR.K,0.75)
47A   TS.K=RAMP(TR.K,0.75)
47A   US.K=RAMP(UR.K,0.75)
47A   VS.K=RAMP(VR.K,0.75)
47A   WS.K=RAMP(WR.K,0.75)
47A   XS.K=RAMP(XR.K,0.75)
47A   YS.K=RAMP(YR.K,0.75)
47A   ZS.K=RAMP(ZR.K,0.75)
34A   AAR.K=(0.916)NORMRN(4,0.8)
34A   BBR.K=(0.951)NORMRN(4,0.8)
34A   OR.K=(0.972)NORMRN(4,0.8)
34A   PR.K=(0.985)NORMRN(4,0.8)
34A   QR.K=(0.992)NORMRN(4,0.8)
34A   RR.K=(0.996)NORMRN(4,0.8)
34A   SR.K=(0.998)NORMRN(4,0.8)
34A   TR.K=(1.002)NORMRN(4,0.8)
34A   UR.K=(1.004)NORMRN(4,0.8)
34A   VR.K=(1.008)NORMRN(4,0.8)
34A   WR.K=(1.015)NORMRN(4,0.8)
34A   XR.K=(1.028)NORMRN(4,0.8)
34A   YR.K=(1.049)NORMRN(4,0.8)
34A   ZR.K=(1.084)NORMRN(4,0.8)
17A   AMSCR.K=(400)(1)(BRIO.K)+(12)(1)(MARO.K)+(6)(1)(RFTO.K)  (   MAX60 RATEAUX
34A   MSCR.K=(AMSCR.K)NORMRN(0.9,0.05)        (   MAX CL 60 CROSSING RATE
12A   AMTCR.K=(6)(LTRO.K)                     (   MIN CL 12 CROSSING RATE AUX
34A   MTCR.K=(AMTCR.K)NORMRN(0.9,0.05)        (   MIN CL TWELVE CROSSING RATE
51A   XDUM.K=CLIP(2.68,2.35,CTSC.K,1313)      (   DUMMY VARIABLE
51A   XRTS.K=CLIP(4.85,XDUM.K,CTSC.K,2038)    (   TACTICAL PLAN PARAMETER
15A   DA1.K=(BRIO.K)(400)+(RFTO.K)(12)
14A   DA2.K=0.0001+(MARO.K)(24)
48A   XCP.K=AMSCR.K/(DA1.K+DA2.K)             (   CROSSING PLAN PARAMETER
14A   DTCS.K=1+(XCP.K)(XRTS.K)
14A   NTCS.K=-MTCR.K+(XRTS.K)(MSCR.K)
20A   TCS.K=NTCS.K/DTCS.K
56A   TCOS.K=MAX(TCS.K,0)                     (   CL 12 VEH XING ON 60 MEANS
14A   ASCC.K=MSCR.K+(TCOS.K)(-XCP.K)          (   ACTUAL CL 60 XING CAPABILITY
7A    ATCA.K=MTCR.K+TCOS.K                    (   CLASS TWELVE CC AUX 1
14A   ATCB.K=MTCR.K+(1.25)(MSCR.K)            (   CLASS TWELVE CC AUX 2 B
51A   ATCC.K=CLIP(ATCB.K,ATCA.K,CSSC.K,1100)  ( CL TWELVE CROSSING CAPABILITY
12A   SVEH.K=(20)(CSID.K)                     (   CLASS SIXTY VEHICLES AVAILAKLE
12A   TVEH.K=(20)(CTID.K)                     (   CLASS TWELVE VEHICLES AVAILABLE
54R   ASCR.KL=MIN(ASCC.K,SVEH.K)              (   ACTUAL CLASS SIXTY XING RATE
6N    ASCR=0                                  (   INITIAL CONDITION
54R   ATCR.KL=MIN(ATCC.K,TVEH.K)              (   ACTUAL CLASS TWELVE XING RATE
6N    ATCR=0                                  (   INITIAL CONDITION
1L    CSID.K=CSID.J+(DT)(SHDR.JK-ASCR.JK)     (   CL SIXTY VEHICLES IN DEFILE
6N    CSID=0                                  (   INITIAL CONDITION
1L    CTID.K=CTID.J+(DT)(THDR.JK-ATCR.JK)     (   CL TWELVE VEHICLES IN DEFILE
6N    CTID=60                                 (   INITIAL CONDITION
54A   SCR.K=MIN(ASCC.K,SVEH.K)                (   SIXTY XING RATE AUX
26A   SDT.K=(ASCC.K-SCR.K+0)/(ASCC.K+1+0)     (   SIXTY DOWN TIME
8A    CSCP.K=BP.K+MBP.K+RP.K                  (   CLASS SIXTY CROSSING PREDICTOR
51A   BP.K=CLIP(0,BPD.K,BCS1.K,1)             (   BRIDGE PREDICTOR
C     BDC1=0.75                               (   BRIDGE DECISION CRITERIA
C     RDX=0.33                                (   RAFT DECISION CRITERIA
51A   BPD.K=CLIP(IMR1.K,0,BCS1.K,BDC1.K)      (   DUMMY VARIABLE
7A    MSC.K=AMSCR.K+0.0001
40A   IMR1.K=-1+(1/MSC.K)(AMSCR.K+400)        (   INCREASED MOVEMENT RATE 1
C     MBP=0                                   (   MOBILE BRIDGE PREDICTOR
10A   RCS1.K=AS.K+BS.K+CS.K+DS.K+ES.K+FS.K
11A   RCS2.K=GS.K+HS.K+IS.K+JS.K+KS.K+LS.K+MS.K+NS.K
21A   RCS.K=(1/14)(RCS1.K+RCS2.K)             (   RAFT CONSTRUCTION STATUS
51A   RP.K=CLIP(0,RPD.K,RCS.K,1)              (   RAFT PREDICTOR
51A   RPD.K=CLIP(IMR2.K,0,RCS.K,RDX.K)        (   DUMMY VARIABLE
40A   IMR2.K=-1+(1/MSC.K)(AMSCR.K+84)         (   INCREASED MOVEMENT RATE 2
43A   SMPT.K=SAMPLE(CSCP.K,0.2)               (   SIXTY MEANS PREDICTED TIME
56A   SMDT.K=MAX(SDT.K,SMPT.K)                (   SIXTY MEANS DOWN TIME AUX
54A   TCR.K=MIN(ATCC.K,TVEH.K)                (   TWELVE XING RATE AUX
26A   TDT.K=(ATCC.K-TCR.K+0)/(ATCC.K+1+0)     (   TWELVE DOWN TIME
7A    TVID.K=CSID.K+CTID.K                    (   TOTAL VEHICLES IN DEFILE
```

Figure 6.2. Listing of Model V.

```
6     XY=18.2                                       (     FIVE MIN LEVEL IN DEFILE
50A   CSDC.K=(XY.K)(CSID.K)/(ASCC.K+0.0001)         (     CL SIXTY DEFILE CONTROL
54A   CSDA.K=MIN(CSDC.K,87)                         )     CL SIXTY DEFILE C AUX
28A   ASDEL.K=(0.1)EXP(CSDA.K)                      )     CLASS SIXTY DELAY
34A   SDEL.K=(ASDEL.K)NORMRN(1,0.04)                (     CLASS SIXTY DELAY
20A   SHR.K=CSHA.K/SDEL.K                           (     SIXTY HA TO DEFILE AUX
51A   SDUM.K=CLIP(ASCC.K,SHR.K,CSSC.K,903)          (     SIXTY DUMMY
7A    SVAL.K=CSSC.K+CSID.K                          (     SIXTY CROSSED PLUS DEFILE
51A   SHRA.K=CLIP(0,SDUM.K,SVAL.K,1109)             (     SIXTY HA TO DEFILE AUX 2
12A   SHAV.K=(20)(CSHA.K)                           (     SIXTY HA AVAILABLE
54R   SHDR.KL=MIN(SHRA.K,SHAV.K)                    (     SIXTY HA TO DEFILE RATE
6N    SHDR=0                                        (     INITIAL CONDITION
47A   CTMS.K=RAMP(THDR.JK,0)                        (     CL TWELVE MOVEMENT STATUS
51A   DUM.K=CLIP(2.68,2.35,CTMS.K,1313)             (     DUMMY VARIABLE
51A   RTS.K=CLIP(4.85,DUM.K,CTMS.K,2038)            (     RATIO TWELVE TO SIXTY
54A   ASHR.K=MIN(SHRA.K,SHAV.K)                     (     CL SIXTY HA RATE AUX
12A   THR.K=(RTS.K)(ASHR.K)                         (     CL 12 HA TO DEFILE RATE AUX
47A   CSMX.K=RAMP(SHDR.JK,0)                        (     CL 60 MOVEMENT STATUS
51A   TDUM.K=CLIP(ATCC.K,THR.K,CSMX.K,1085)         (     B DUMMY
7A    TVAL.K=CTSC.K+CTID.K                          (     TWELVE CROSSED PLUS DEFILE
51A   THRA.K=CLIP(0,TDUM.K,TVAL.K,3389)             (     CL TWELVE HA RATE AUX
12A   THAV.K=(20)(CTHA.K)                           (     TWELVE HA AVAILABLE
54R   THDR.KL=MIN(THRA.K,THAV.K)                    (     TWELVE HA TC DEFILE RATE
6N    THDR=0                                        (     INITIAL CONDITION
52L   CSHA.K=CSHA.J+(DT)(SHAR1.JK+SHAR2.JK+SHAR3.JK-SHDR.JK) ( CL 60 VEH IN HA
6N    CSHA=42                                       (     INITIAL CONDITION
52L   CTHA.K=CTHA.J+(DT)(THAR1.JK+THAR2.JK+THAR3.JK-THDR.JK) ( CL 12 VEH IN HA
6N    CTHA=140                                      (     INITIAL CONDITION
7A    TVHA.K=CSHA.K+CTHA.K                          (     TOTAL VEH IN HOLDING AREAS
1L    CSMV1.K=CSMV1.J+(DT)(SDHR1.JK-SHAR1.JK)       (  CL SIXTY MOVEMENT LEVEL 1
6N    CSMV1=0                                       (     INITIAL CONDITION
1L    CSMV2.K=CSMV2.J+(DT)(SDHR2.JK-SHAR2.JK)       (  CL SIXTY MOVEMENT LEVEL 2
6N    CSMV2=0                                       (     INITIAL CONDITION
1L    CSMV3.K=CSMV3.J+(DT)(SDHR3.JK-SHAR3.JK)       (  CL SIXTY MOVEMENT LEVEL 3
6N    CSMV3=0                                       (     INITIAL CONDITION
3S    CSMV.K=CSMV1.K+CSMV2.K+CSMV3.K                (     CL SIXTY MOVEMENT LEVEL
12A   SAVL1.K=(20)(CSMV1.K)                         (     CL SIXTY MVMT AVAILABLE 1
12A   SAVL2.K=(20)(CSMV2.K)                         (     CL SIXTY MVMT AVAILABLE 2
12A   SAVL3.K=(20)(CSMV3.K)                         (     CL SIXTY MVMT AVAILABLE 3
39R   CSMR1.KL=DELAY3(SDHR1.JK,0.45)                (     CL SIXTY MOVEMENT RATE 1
39R   CSMR2.KL=DELAY3(SDHR2.JK,0.70)                (     CL SIXTY MOVEMENT RATE 2
39R   CSMR3.KL=DELAY3(SDHR3.JK,0.95)                (     CL SIXTY MOVEMENT RATE 3
3S    CSMR.K=CSMR1.JK+CSMR2.JK+CSMR3.JK                   CL SIXTY MVMT RATE
6A    SOT1.K=CSMR1.JK                               (     CL SIXTY HA ARR RATE 1 AUX 1
6A    SOT2.K=CSMR2.JK                               (     CL SIXTY HA ARR RATE 2 AUX 1
6A    SOT3.K=CSMR3.JK                               (     CL SIXTY HA ARR RATE 3 AUX 1
34A   SOU1.K=(SOT1.K)NORMRN(1,0.25)                 (     CL SIXTY HA ARR RATE 1 AUX 2
34A   SOU2.K=(SOT2.K)NORMRN(1,0.25)                 (     CL SIXTY HA ARR RATE 2
34A   SOU3.K=(SOT3.K)NORMRN(1,0.25)                 (     CL SIXTY HA ARR RATE 3
56A   SOUT1.K=MAX(SOU1.K,0)                         (     CL SIXTY HA ARR RATE 1 AUX 3
56A   SOUT2.K=MAX(SOU2.K,0)                         (     CL SIXTY HA ARR RATE 2 AUX 3
56A   SOUT3.K=MAX(SOU3.K,0)                         (     CL SIXTY HA ARR RATE 3 AUX 3
51R   SHAR1.KL=CLIP(SOUT1.K,SAVL1.K,CSD.K,50)       (  CL SIXTY HA ARRIVAL RATE 1
6N    SHAR1=0                                       (     INITIAL CONDITION
51R   SHAR2.KL=CLIP(SOUT2.K,SAVL2.K,CSD.K,50)       (  CL SIXTY HA ARRIVAL RATE 2
6N    SHAR2=0                                       (     INITIAL CONDITION
51R   SHAR3.KL=CLIP(SOUT3.K,SAVL3.K,CSD.K,50)       (  CL SIXTY HA ARRIVAL RATE 3
6N    SHAR3=0                                       (     INITIAL CONDITION
51A   SHA1.K=CLIP(SOUT1.K,SAVL1.K,CSD.K,50)         (     CL SIXTY HA ARR RATE 1 AUX 5
51A   SHA2.K=CLIP(SOUT2.K,SAVL2.K,CSD.K,50)         (     CL SIXTY HA ARR RATE 2 AUX 5
51A   SHA3.K=CLIP(SOUT3.K,SAVL3.K,CSD.K,50)         (     CL SIXTY HA ARR RATE 3 AUX 5
3S    SHA.K=SHA1.K+SHA2.K+SHA3.K                    (     CL SIXTY HA ARRIVAL RATE
1L    CTMV1.K=CTMV1.J+(DT)(TDHR1.JK-THAR1.JK)       (  CL TWELVE MOVEMENT LEVEL 1
6N    CTMV1=0                                       (     INITIAL CONDITION
1L    CTMV2.K=CTMV2.J+(DT)(TDHR2.JK-THAR2.JK)       (  CL TWELVE MOVEMENT LEVEL 2
6N    CTMV2=0                                       (     INITIAL CONDITION
1L    CTMV3.K=CTMV3.J+(DT)(TDHR3.JK-THAR3.JK)       (  CL TWELVE MOVEMENT LEVEL 3
6N    CTMV3=0                                       (     INITIAL CONDITION
3S    CTMV.K=CTMV1.K+CTMV2.K+CTMV3.K                (     CL TWELVE MOVEMENT LEVEL
39R   CTMR1.KL=DELAY3(TDHR1.JK,0.45)                (     CL TWELVE MOVEMENT RATE 1
39R   CTMR2.KL=DELAY3(TDHR2.JK,0.70)                (     CL TWELVE MOVEMENT RATE 2
39R   CTMR3.KL=DELAY3(TDHR3.JK,0.95)                (     CL TWELVE MOVEMENT RATE 3
3S    CTMR.K=CTMR1.JK+CTMR2.JK+CTMR3.JK                   CL TWELVE MVMT RATE
12A   TAVL1.K=(20)(CTMV1.K)                         (     CL TWELVE MVMT AVAILABLE 1
12A   TAVL2.K=(20)(CTMV2.K)                         (     CL TWELVE MVMT AVAILABLE 2
12A   TAVL3.K=(20)(CTMV3.K)                         (     CL TWELVE MVMT AVAILABLE 3
```

Figure 6.3. Listing of Model V.

```
6A    TOT1.K=CTMR1.JK                                  (  CL TWELVE HA ARR RATE 1 AUX 2
6A    TOT2.K=CTMR2.JK                                  (  CL TWELVE HA ARR RATE 2 AUX 2
6A    TOT3.K=CTMR3.JK                                  (  CL TWELVE HA ARR RATE 3 AUX 2
34A   TOU1.K=(TOT1.K)NORMRN(1,0.25)                    (  CL TWELVE HA ARR RATE 1 AUX 1
34A   TOU2.K=(TOT2.K)NORMRN(1,0.25)                    (  CL TWELVE HA ARR RATE 2 AUX 1
34A   TOU3.K=(TOT3.K)NORMRN(1,0.25)                    (  CL TWELVE HA ARR RATE 3 AUX 1
56A   TOUT1.K=MAX(TOU1.K,0)                            (  CL TWELVE HA ARR RATE 1 AUX 3
56A   TOUT2.K=MAX(TOU2.K,0)                            (  CL TWELVE HA ARR RATE 2 AUX 3
56A   TOUT3.K=MAX(TOU3.K,0)                            (  CL TWELVE HA ARR RATE 3 AUX 3
51R   THAR1.KL=CLIP(TOUT1.K,TAVL1.K,CTD.K,223) (  CL TWELVE HA ARR RATE 1
6N    THAR1=0                                          (  INITIAL CONDITION
51R   THAR2.KL=CLIP(TOUT2.K,TAVL2.K,CTD.K,223) (  CL TWFLVE HA ARR RATE 2
6N    THAR2=0                                          (  INITIAL CONCITION
51R   THAR3.KL=CLIP(TOUT3.K,TAVL3.K,CTD.K,223) (  CL TWELVE HA ARR RATE 3
6N    THAR3=0                                          (  INITIAL CONCITION
51A   THA1.K=CLIP(TOUT1.K,TAVL1.K,CTD.K,223)    (  CL TWELVE HA ARR RATE 1 AUX 5
51A   THA2.K=CLIP(TOUT2.K,TAVL2.K,CTD.K,223)    (  CL TWELVE HA ARR RATE 2 AUX 5
51A   THA3.K=CLIP(TOUT3.K,TAVL3.K,CTD.K,223)    (  CL TWELVE HA ARR RATE 3 AUX 5
8S    THAR.K=THA1.K+THA2.K+THA3.K                      (  CL TWELVE HA ARRIVAL RATE
18A   ASDH.K=(ASCC.K)(1+SMDT.K)                        (  CL SIXTY DEPLOYED TO HA AUX
51A   DUMY.K=CLIP(2.68,4.85,CTD.K,1351)                (  DUMMY VARIABLE
51A   RTTS.K=CLIP(2.35,DUMY.K,CTD.K,2076)              (  RATIO CL TWELVE TO CLASS SIXTY
12A   CSAV.K=(20)(CSD.K)                               (  SIXTY DEPLOYED TO HA AUX
54A   SDHR.K=MIN(CSAV.K,ASDH.K)                        (  CL SIXTY DEPLOYED TC HA AUX
12R   SDHR1.KL=(0.25)(SDHR.K)                          (  CL SIXTY DEPLOYED TO HA RATE 1
6N    SDHR1=0                                          (  INITIAL CONCITION
12R   SDHR2.KL=(0.5)(SDHR.K)                           (  CL SIXTY DEPLOYED TO HA RATE 2
6N    SDHR2=0                                          (  INITIAL CONDITION
12R   SDHR3.KL=(0.25)(SDHR.K)                          (  CL SIXTY DEPLOYED TO HA RATE 3
6N    SDHR3=0                                          (  INITIAL CONCITION
54A   ASDR.K=MIN(CSAV.K,ASDH.K)                        (  CL SIXTY DEPLOYED HA RATE AUX
12A   AMR.K=(RTTS.K)(ASDR.K)                           (  ADJUSTED CL TWELVE MVMT RATE AU
51A   ATMR.K=CLIP(AMR.K,ATCC.K,CSD.K,25)               (  B
12A   CTAV.K=(20)(CTD.K)                               (  TWELVE DEPLCYED TO HA AUX
54A   TDHR.K=MIN(CTAV.K,ATMR.K)                        (  CL 12 DEPLOYED TO HA RATE
12R   TDHR1.KL=(0.25)(TDHR.K)                          (  CL TWELVE DEPLOYED TO HA RATE 1
6N    TDHR1=0                                          (  INITIAL CONCITION
6N    TDHR2=0                                          (  INITIAL CONCITION
12R   TDHR2.KL=(0.5)(TDHR.K)                           (  CL TWELVE DEPLOYED TO HA RATE 2
6N    TDHR3=0                                          (  INITIAL CONCITION
12R   TDHR3.KL=(0.25)(TDHR.K)                          (  CL TWELVE DEPLOYED TO HA RATE 3
52L   CSD.K=CSD.J+(DT)(0-SDHR1.JK-SDHR2.JK-SDHR3.JK) ( CL SIXTY VEH DEPLOYED
6N    CSD=1067                                         (  INITIAL CONCITION
52L   CTD.K=CTD.J+(DT)(0-TDHR1.JK-TDHR2.JK-TDHR3.JK) ( CL TWELVE VEH DEPLOYED
6N    CTD=3189                                         (  INITIAL CONDITION
1L    CSSC.K=CSSC.J+(DT)(ASCR.JK+0)                    (  CL SIXTY VEH SUCCESS CROSSED
6N    CSSC=0                                           (  INITIAL CONCITION
1L    CTSC.K=CTSC.J+(DT)(ATCR.JK+0)                    (  CL TWELVE VEH SUCCESS CROSSED
6N    CTSC=0                                           (  INITIAL CONDITION
48S   RSHC.K=CSHA.K/(ASCC.K+1)                         (  SIXTY HA XING RATIO
48S   RTHC.K=CTHA.K/(ATCC.K+1)                         (  TWELVE HA XING RATIO
48S   RSDC.K=CSID.K/(ASCC.K+1)                         (  SIXTY DEFILE XING RATIO
48S   RTDC.K=CTID.K/(ATCC.K+1)                         (  TWELVE DEFILE XING RATIO
40A   TCC.K=MSCR.K+(1/2)(MTCR.K+1)
20S   RDC.K=TVID.K/TCC.K                               (  RATIO DEFILE TO CC
20S   RHC.K=TVHA.K/TCC.K                               (  RATIO HA TO CROSSING CAP
47A   DCL.K=RAMP(TVID.K,6.5)                           )  DEFILE CONC LEVEL
47A   DCLN.K=RAMP(1,6.5)                               )  DEFILE CONC LEVEL N
48S   ATVID.K=DCL.K/(DCLN.K+0.0001)                    )  CUM AVE VEH IN DEFILE
47A   HACL.K=RAMP(TVHA.K,6.5)                          )  HA CONC LEVEL
48S   ATVHA.K=HACL.K/(DCLN.K+0.0001)                   )  CUM AVE VEH IN HA
47A   SDM.K=RAMP(SDT.K,0)                              )  SIXTY DOWN TIME LEVEL
47A   TDM.K=RAMP(TDT.K,0)                              )  TWELV DOWN TIME LEVEL
48S   ASDT.K=SDM.K/(CLDK.K+0.0001)                     )  CUM AVE 60 COWN TIME
48S   ATDT.K=TDM.K/(CLDK.K+0.0001)                     )  CUM AVE 12 DOWN TIME
PRINT 1)SDT/2)TDT/3)TVID/4)TVHA/5)SHDR/6)THDR/7)SDHR/8)TDHR/9)SHAR
PRINT 1)RSHC/2)RTHC/3)RSDC/4)RTDC/5)CSSC/6)CTSC/7)CSD/8)CTD/9)CSMV
PRINT 1)RHC/2)RDC/3)CSHA/4)CTHA/5)ASCR/6)ATCR/7)TCOS/8)CTMV/9)THAR
PRINT 1)ATVID/2)ATVHA/3)ASDT/4)ATDT/5)CSMR/6)CTMR/7)SDEL
PRINT 1)BRIO/2)MARO/3)RFTO/4)LTRO/5)MSCR/6)MTCR
PLOT  CSSC=S(0,1400)/CTSC=T(0,3900)/ASCR=R/ATCR=P/TVID=C
PLOT  SMPT=A/SDT=G/TDT=I/SDEL=D(0,10)/TVHA=H/CSID=J/CTID=K
PLOT  BRIO=B/MARO=M/RFTO=E/LTRO=L/MSCR=U/MTCR=V/TCOS=Z
SPEC  DT=0.05/LENGTH=16/PRTPER=0.10/PLTPER=0.10
```

Figure 6.4. Listing of Model V.

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        ASSAULT RIVER CROSSING,IE700, REED + DAVIS, DR JOSEPH KOHL
        MODEL VI PLAN E
        RANDOM OUTAGES OF CROSSING MEANS
        PREDICTION BASED ON CONSTRUCTION STATUS
        CONSTRUCTION POSITION ADDED
        FIVE MINUTE LEVEL IN DEFILE
        SIXTY MINUTE PREDICTIVE CAPABILITY
1L      CLOK.K=CLOK.J+(DT)(1+0)                       (     PROBLEM TIME
6N      CLOK=0                                        (     INITIAL CONDITION
43A     BRIO.K=SAMPLE(BRINA.K,0.1)                    (     BRIDGES IN OPERATION
7A      BRIN.K=BRIN1.K+BRIN2.K
51A     BRIN1.K=CLIP(1,0,BCS1.K,1)
51A     BRIN2.K=CLIP(1,0,BCS2.K,1)
47A     BCS1.K=RAMP(BCR1.K,2.5)
47A     BCS2.K=RAMP(BCR2.K,2.5)
44A     BCR1.K=(1)NORMRN(0.25,0.05)
44A     BCR2.K=(1)NORMRN(0.67,0.12)
43A     MARO.K=SAMPLE(MRINA.K,0.1)                    (     MOBILE ASSAULT RAFTS IN OPN
7A      MRIN.K=MRIN1.K+MRIN2.K+MRIN3.K+MRIN4.K
51A     MRIN1.K=CLIP(MAR1.K,0,MRCS1.K,1)
51A     MRIN2.K=CLIP(MAR2.K,0,MRCS2.K,1)
51A     MRIN3.K=CLIP(MAR3.K,0,MRCS3.K,1)
51A     MRIN4.K=CLIP(MAR4.K,0,MRCS4.K,1)
51A     MAR1.K=CLIP(0,1,CLOK.K,2.5)
51A     MAR2.K=CLIP(0,1,CLOK.K,2.5)
51A     MAR3.K=CLIP(0,1,CLOK.K,2.5)
51A     MAR4.K=CLIP(0,1,CLOK.K,2.5)
47A     MRCS1.K=RAMP(MRCR1.K,1)
47A     MRCS2.K=RAMP(MRCR2.K,1)
47A     MRCS3.K=RAMP(MRCR3.K,1)
47A     MRCS4.K=RAMP(MRCR4.K,1)
44A     MRCR1.K=(0.95)NORMRN(2,0.4)
44A     MRCR2.K=(0.98)NORMRN(2,0.4)
44A     MRCR3.K=(1.02)NORMRN(2,0.4)
44A     MRCR4.K=(1.05)NORMRN(2,0.4)
43A     RFTO.K=SAMPLE(RFINA.K,0.1)                    (     M4T6 RAFTS IN OPERATION
7A      RFIN.K=RFIN1.K+RFIN2.K
10A     RFIN1.K=A.K+B.K+C.K+D.K+E.K+F.K
11A     RFIN2.K=G.K+H.K+I.K+J.K+K.K+L.K+M.K+N.K
51A     A.K=CLIP(1,0,AS.K,1)
51A     B.K=CLIP(1,0,BS.K,1)
51A     C.K=CLIP(1,0,CS.K,1)
51A     D.K=CLIP(1,0,DS.K,1)
51A     E.K=CLIP(1,0,ES.K,1)
51A     F.K=CLIP(1,0,FS.K,1)
51A     G.K=CLIP(1,0,GS.K,1)
51A     H.K=CLIP(1,0,HS.K,1)
51A     I.K=CLIP(1,0,IS.K,1)
51A     J.K=CLIP(1,0,JS.K,1)
51A     K.K=CLIP(1,0,KS.K,1)
51A     L.K=CLIP(1,0,LS.K,1)
51A     M.K=CLIP(1,0,MS.K,1)
51A     N.K=CLIP(1,0,NS.K,1)
47A     AS.K=RAMP(AR.K,1)
47A     BS.K=RAMP(BR.K,1)
47A     CS.K=RAMP(CR.K,1)
47A     DS.K=RAMP(DR.K,1)
47A     ES.K=RAMP(ER.K,1)
47A     FS.K=RAMP(FR.K,1)
47A     GS.K=RAMP(GR.K,1)
47A     HS.K=RAMP(HR.K,1)
47A     IS.K=RAMP(IR.K,1)
47A     JS.K=RAMP(JR.K,1)
47A     KS.K=RAMP(KR.K,1)
47A     LS.K=RAMP(LR.K,1)
47A     MS.K=RAMP(MR.K,1)
47A     NS.K=RAMP(NR.K,1)
44A     AR.K=(0.916)NORMRN(0.67,0.14)
44A     BR.K=(0.951)NORMRN(0.67,0.14)
44A     CR.K=(0.972)NORMRN(0.67,0.14)
44A     DR.K=(0.985)NORMRN(0.67,0.14)
44A     ER.K=(0.992)NORMRN(0.67,0.14)
44A     FR.K=(0.996)NORMRN(0.67,0.14)
44A     GR.K=(0.998)NORMRN(0.67,0.14)
44A     HR.K=(1.002)NORMRN(0.67,0.14)
44A     IR.K=(1.004)NORMRN(0.67,0.14)
44A     JR.K=(1.008)NORMRN(0.67,0.14)
44A     KR.K=(1.015)NORMRN(0.67,0.14)
44A     LR.K=(1.028)NORMRN(0.67,0.14)
44A     MR.K=(1.049)NORMRN(0.67,0.14)
44A     NR.K=(1.084)NORMRN(0.67,0.14)
43A     LTRO.K=SAMPLE(LRINA.K,0.1)                    (     LIGHT TACTICAL RAFTS IN OPN
7A      LRIN.K=LRIN1.K+LRIN2.K
10A     LRIN1.K=AA.K+BB.K+O.K+P.K+Q.K+R.K
11A     LRIN2.K=S.K+T.K+U.K+V.K+W.K+X.K+Y.K+Z.K
51A     AA.K=CLIP(1,0,AAS.K,1)
```

Figure 7.1. Listing of Model VI.

```
51A    BB.K=CLIP(1,0,BBS.K,1)
51A    O.K=CLIP(1,0,OS.K,1)
51A    P.K=CLIP(1,0,PS.K,1)
51A    Q.K=CLIP(1,0,QS.K,1)
51A    R.K=CLIP(1,0,RS.K,1)
51A    S.K=CLIP(1,0,SS.K,1)
51A    T.K=CLIP(1,0,TS.K,1)
51A    U.K=CLIP(1,0,US.K,1)
51A    V.K=CLIP(1,0,VS.K,1)
51A    W.K=CLIP(1,0,WS.K,1)
51A    X.K=CLIP(1,0,XS.K,1)
51A    Y.K=CLIP(1,0,YS.K,1)
51A    Z.K=CLIP(1,0,ZS.K,1)
47A    AAS.K=RAMP(AAR.K,0.75)
47A    BBS.K=RAMP(BBR.K,0.75)
47A    OS.K=RAMP(OR.K,0.75)
47A    PS.K=RAMP(PR.K,0.75)
47A    QS.K=RAMP(QR.K,0.75)
47A    RS.K=RAMP(RR.K,0.75)
47A    SS.K=RAMP(SR.K,0.75)
47A    TS.K=RAMP(TR.K,0.75)
47A    US.K=RAMP(UR.K,0.75)
47A    VS.K=RAMP(VR.K,0.75)
47A    WS.K=RAMP(WR.K,0.75)
47A    XS.K=RAMP(XR.K,0.75)
47A    YS.K=RAMP(YR.K,0.75)
47A    ZS.K=RAMP(ZR.K,0.75)
44A    AAR.K=(0.916)NORMRN(4,0.8)
44A    BBR.K=(0.951)NORMRN(4,0.8)
44A    OR.K=(0.972)NORMRN(4,0.8)
44A    PR.K=(0.985)NORMRN(4,0.8)
44A    QR.K=(0.992)NORMRN(4,0.8)
44A    RR.K=(0.996)NORMRN(4,0.8)
44A    SR.K=(0.998)NORMRN(4,0.8)
44A    TR.K=(1.002)NORMRN(4,0.8)
44A    UR.K=(1.004)NORMRN(4,0.8)
44A    VR.K=(1.008)NORMRN(4,0.8)
44A    WR.K=(1.015)NORMRN(4,0.8)
44A    XR.K=(1.028)NORMRN(4,0.8)
44A    YR.K=(1.049)NORMRN(4,0.8)
44A    ZR.K=(1.084)NORMRN(4,0.8)
54A    BRINA.K=MIN(BRIN.K,BROUT.K)
54A    MRINA.K=MIN(MRIN.K,MROUT.K)
54A    RFINA.K=MIN(RFIN.K,RFOUT.K)
54A    LRINA.K=MIN(LRIN.K,LROUT.K)
44A    BRR.K=(1)NORMRN(1,0.2)                  (    BRIDGE REPAIR RATE
44A    MRRR.K=(1)NORMRN(0.25,0.06)             (    MOBILE RAFT REPAIR RATE
44A    RRR.K=(1)NORMRN(0.5,0.1)                (    M4T6 RAFT REPAIR RATE
44A    LRRR.K=(1)NORMRN(0.15,0.02)             (    LTR REPAIR RATE
43A    BROUT.K=SAMPLE(BROT.K,BRR.K)
43A    MROUT.K=SAMPLE(MROT.K,MRRR.K)
43A    RFOUT.K=SAMPLE(RFOT.K,RRR.K)
43A    LROUT.K=SAMPLE(LROT.K,LRRR.K)
33A    RNB.K=(1)NOISE
45A    RNA.K=STEP(RNB.K,1)
7A     RN.K=RNA.K+0.5
51A    BROT.K=CLIP(2,BROT1.K,RN.K,0.19)
51A    BROT1.K=CLIP(1,0,RN.K,0.01)
51A    MROT.K=CLIP(4,MROT1.K,RN.K,0.15)
51A    MROT1.K=CLIP(3,MROT2.K,RN.K,0.01)
51A    MROT2.K=CLIP(2,1,RN.K,0.0001)
51A    RFOT.K=CLIP(14,RFOT1.K,RN.K,0.77)
51A    RFOT1.K=CLIP(13,RFOT2.K,RN.K,0.413)
51A    RFOT2.K=CLIP(12,RFOT3.K,RN.K,0.155)
51A    RFOT3.K=CLIP(11,RFOT4.K,RN.K,0.041)
51A    RFOT4.K=CLIP(10,9,RN.K,0.006)
51A    LROT.K=CLIP(14,LROT1.K,RN.K,0.512)
51A    LROT1.K=CLIP(13,LROT2.K,RN.K,0.151)
51A    LROT2.K=CLIP(12,LROT3.K,RN.K,0.029)
51A    LROT3.K=CLIP(11,10,RN.K,0.003)
17A    AMSCR.K=(400)(1)(BRID.K)+(12)(1)(MARO.K)+(6)(1)(RFTO.K)   (  MAX60 RATEAUX
44A    MSCR.K=(AMSCR.K)NORMRN(0.9,0.05)        (    MAX CL 60 CROSSING RATE
12A    AMTCR.K=(6)(LTRO.K)                     (    MIN CL 12 CROSSING RATE AUX
44A    MTCR.K=(AMTCR.K)NORMRN(0.9,0.05)        (    MIN CL TWELVE CROSSING RATE
51A    XDUM.K=CLIP(2.68,2.35,CTSC.K,1313)      (    DUMMY VARIABLE
51A    XRTS.K=CLIP(4.85,XDUM.K,CTSC.K,2038)    (    TACTICAL PLAN PARAMETER
15A    DA1.K=(BRID.K)(400)+(RFTO.K)(12)
14A    DA2.K=0.0001+(MARO.K)(24)
43A    XCP.K=AMSCR.K/(DA1.K+DA2.K)             (    CROSSING PLAN PARAMETER
14A    DTCS.K=1+(XCP.K)(XRTS.K)
14A    NTCS.K=-MTCR.K+(XRTS.K)(MSCR.K)
20A    TCS.K=NTCS.K/DTCS.K
56A    TCOS.K=MAX(TCS.K,0)                     (    CL 12 VEH XING ON 60 MEANS
14A    ASCC.K=MSCR.K+(TCOS.K)(-XCP.K)          (    ACTUAL CL 60 XING CAPABILITY
7A     ATCA.K=MTCR.K+TCOS.K                    (    CLASS TWELVE CC AUX 1
14A    ATC3.K=MTCR.K+(1.1)(MSCR.K)             (    CLASS TWELVE CC AUX 2 E
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Figure 7.2. Listing of Model VI.

```
51A  ATCC.K=CLIP(ATCB.K,ATCA.K,CSSC.K,1100)    ( CL TWELVE CROSSING CAPABILITY
12A  SVEH.K=(20)(CSID.K)                        (   CLASS SIXTY VEHICLES AVAILABLE
12A  TVEH.K=(20)(CTID.K)                        (   CLASS TWELVE VEHICLES AVAILABLE
54R  ASCR.KL=MIN(ASCC.K,SVEH.K)                 (   ACTUAL CLASS SIXTY XING RATE
6N   ASCR=0                                     (   INITIAL CONDITION
54R  ATCR.KL=MIN(ATCC.K,TVEH.K)                 (   ACTUAL CLASS TWELVE XING RATE
6N   ATCR=0                                     (   INITIAL CONDITION
1L   CSID.K=CSID.J+(DT)(SHDR.JK-ASCR.JK)        (   CL SIXTY VEHICLES IN DEFILE
6N   CSID=0                                     (   INITIAL CONDITION
1L   CTID.K=CTID.J+(DT)(THDR.JK-ATCR.JK)        (   CL TWELVE VEHICLES IN DEFILE
6N   CTID=60                                    (   INITIAL CONDITION
54A  SCR.K=MIN(ASCC.K,SVEH.K)                   (   SIXTY XING RATE AUX
20A  SDT.K=(ASCC.K-SCR.K+0)/(ASCC.K+1+0)        (   SIXTY DOWN TIME
7A   CSCP.K=BP.K+MBP.K+RP.K                     (   CLASS SIXTY CROSSING PREDICTOR
51A  BP.K=CLIP(0,BPD.K,BCS1.K,1)                (   BRIDGE PREDICTOR
C    BDC1=0.75                                  (   BRIDGE DECISION CRITERIA
51A  BPD.K=CLIP(IMR1.K,0,BCS1.K,BDC1.K)         (   DUMMY VARIABLE
7A   MSC.K=AMSCR.K+0.0001
40A  IMR1.K=-1+(1/MSC.K)(AMSCR.K+400)           (   INCREASED MOVEMENT RATE 1
51A  MBP.K=CLIP(0,MBPD.K,BCS2.K,1)              (   MOBILE BRIDGE PREDICTOR
51A  MBPD.K=CLIP(IMR1.K,0,BCS2.K,BDC2.K)        (   DUMMY VARIABLE
C    BDC2=0.33                                  (   MOBILE BRIDGE DECISION CRITERIA
10A  RCS1.K=AS.K+BS.K+CS.K+DS.K+ES.K+FS.K
11A  RCS2.K=GS.K+HS.K+IS.K+JS.K+KS.K+LS.K+MS.K+NS.K
21A  RCS.K=(1/14)(RCS1.K+RCS2.K)                (   RAFT CONSTRUCTION STATUS
51A  RP.K=CLIP(0,RPD.K,RCS.K,1)                 (   RAFT PREDICTOR
C    RDX=0.33                                   (   RAFT DECISION CRITERIA
51A  RPD.K=CLIP(IMR2.K,0,RCS.K,RDX.K)           (   DUMMY VARIABLE
40A  IMR2.K=-1+(1/MSC.K)(AMSCR.K+84)            (   INCREASED MOVEMENT RATE 2
43A  SMPT.K=SAMPLE(CSCP.K,0.2)                  (   SIXTY MEANS PREDICTED TIME
56A  SMDT.K=MAX(SDT.K,SMPT.K)                   (   SIXTY MEANS DOWN TIME AUX
54A  TCR.K=MIN(ATCC.K,TVEH.K)                   (   TWELVE XING RATE AUX
20A  TDT.K=(ATCC.K-TCR.K+0)/(ATCC.K+1+0)        (   TWELVE DOWN TIME
7A   TVID.K=CSID.K+CTID.K                       (   TOTAL VEHICLES IN DEFILE
C    XY=18.2                                    (   FIVE MIN LEVEL IN DEFILE
50A  CSDC.K=(XY.K)(CSID.K)/(ASCC.K+0.0001)      (   CL SIXTY DEFILE CONTROL
54A  CSDB.K=MIN(CSDC.K,67)                      )   CL SIXTY DEFILE C AUX
24A  ASDEL.K=(0.1)EXP(CSDB.K)                   )   CLASS SIXTY DELAY
34A  SDEL.K=(ASDEL.K)NORMRN(1,0.04)             (   CLASS SIXTY DELAY
20A  SHR.K=CSHA.K/SDEL.K                        (   SIXTY HA TO DEFILE AUX
51A  SDUM.K=CLIP(ASCC.K,SHR.K,CSSC.K,903)       (   SIXTY DUMMY
7A   SVAL.K=CSSC.K+CSID.K                       (   SIXTY CROSSED PLUS DEFILE
51A  SHRA.K=CLIP(0,SDUM.K,SVAL.K,1109)          (   SIXTY HA TO DEFILE AUX 2
12A  SHAV.K=(20)(CSHA.K)                        (   SIXTY HA AVAILABLE
54R  SHDR.KL=MIN(SHRA.K,SHAV.K)                 (   SIXTY HA TO DEFILE RATE
6N   SHDR=0                                     (   INITIAL CONDITION
47A  CTMS.K=RAMP(THDR.JK,0)                     (   CL TWELVE MOVEMENT STATUS
51A  DUM.K=CLIP(2.68,2.35,CTMS.K,1313)          (   DUMMY VARIABLE
51A  RTS.K=CLIP(4.85,DUM.K,CTMS.K,2038)         (   RATIO TWELVE TO SIXTY
54A  ASHR.K=MIN(SHRA.K,SHAV.K)                  (   CL SIXTY HA RATE AUX
12A  THR.K=(RTS.K)(ASHR.K)                      (   CL 12 HA TO DEFILE RATE AUX
47A  CSMX.K=RAMP(SHDR.JK,0)                     (   CL 60 MOVEMENT STATUS
51A  TDUM.K=CLIP(ATCC.K,THR.K,CSMX.K,1065)      (   E DUMMY
7A   TVAL.K=CTSC.K+CTID.K                       (   TWELVE CROSSED PLUS DEFILE
51A  THRA.K=CLIP(0,TDUM.K,TVAL.K,3389)          (   CL TWELVE HA RATE AUX
12A  THAV.K=(20)(CTHA.K)                        (   TWELVE HA AVAILABLE
54R  THDR.KL=MIN(THRA.K,THAV.K)                 (   TWELVE HA TO DEFILE RATE
6N   THDR=0                                     (   INITIAL CONDITION
52L  CSHA.K=CSHA.J+(DT)(SHAR1.JK+SHAR2.JK+SHAR3.JK-SHDR.JK) ( CL 60 VEH IN HA
6N   CSHA=42                                    (   INITIAL CONDITION
52L  CTHA.K=CTHA.J+(DT)(THAR1.JK+THAR2.JK+THAR3.JK-THDR.JK) ( CL 12 VEH IN HA
6N   CTHA=140                                   (   INITIAL CONDITION
7A   TVHA.K=CSHA.K+CTHA.K                       (   TOTAL VEH IN HOLDING AREAS
1L   CSMV1.K=CSMV1.J+(DT)(SDHR1.JK-SHAR1.JK)    ( CL SIXTY MOVEMENT LEVEL 1
6N   CSMV1=0                                    (   INITIAL CONDITION
1L   CSMV2.K=CSMV2.J+(DT)(SDHR2.JK-SHAR2.JK)    ( CL SIXTY MOVEMENT LEVEL 2
6N   CSMV2=0                                    (   INITIAL CONDITION
1L   CSMV3.K=CSMV3.J+(DT)(SDHR3.JK-SHAR3.JK)    ( CL SIXTY MOVEMENT LEVEL 3
6N   CSMV3=0                                    (   INITIAL CONDITION
3S   CSMV.K=CSMV1.K+CSMV2.K+CSMV3.K             (   CL SIXTY MOVEMENT LEVEL
12A  SAVL1.K=(20)(CSMV1.K)                      (   CL SIXTY MVMT AVAILABLE 1
12A  SAVL2.K=(20)(CSMV2.K)                      (   CL SIXTY MVMT AVAILABLE 2
12A  SAVL3.K=(20)(CSMV3.K)                      (   CL SIXTY MVMT AVAILABLE 3
39R  CSMR1.KL=DELAY3(SDHR1.JK,0.45)             (   CL SIXTY MOVEMENT RATE 1
39R  CSMR2.KL=DELAY3(SDHR2.JK,0.70)             (   CL SIXTY MOVEMENT RATE 2
39R  CSMR3.KL=DELAY3(SDHR3.JK,0.95)             (   CL SIXTY MOVEMENT RATE 3
3S   CSMR.K=CSMR1.JK+CSMR2.JK+CSMR3.JK              CL SIXTY MVMT RATE
6A   SOT1.K=CSMR1.JK                            (   CL SIXTY HA ARR RATE 1 AUX 1
6A   SOT2.K=CSMR2.JK                            (   CL SIXTY HA ARR RATE 2 AUX 1
6A   SOT3.K=CSMR3.JK                            (   CL SIXTY HA ARR RATE 3 AUX 1
34A  SOU1.K=(SOT1.K)NORMRN(1,0.25)              (   CL SIXTY HA ARR RATE 1 AUX 2
34A  SOU2.K=(SOT2.K)NORMRN(1,0.25)              (   CL SIXTY HA ARR RATE 2
34A  SOU3.K=(SOT3.K)NORMRN(1,0.25)              (   CL SIXTY HA ARR RATE 3
56A  SOUT1.K=MAX(SOU1.K,0)                      (   CL SIXTY HA RATE 1 AUX 3
56A  SOUT2.K=MAX(SOU2.K,0)                      (   CL SIXTY HA ARR RATE 2 AUX 3
56A  SOUT3.K=MAX(SOU3.K,0)                      (   CL SIXTY HA ARR RATE 3 AUX 3
51R  SHAR1.KL=CLIP(SOUT1.K,SAVL1.K,CSD.K,50)    ( CL SIXTY HA ARRIVAL RATE 1
6N   SHAR1=0                                    (   INITIAL CONDITION
51R  SHAR2.KL=CLIP(SOUT2.K,SAVL2.K,CSD.K,50)    ( CL SIXTY HA ARRIVAL RATE 2
6N   SHAR2=0                                    (   INITIAL CONDITION
51R  SHAR3.KL=CLIP(SOUT3.K,SAVL3.K,CSD.K,50)    ( CL SIXTY HA ARRIVAL RATE 3
6N   SHAR3=0                                    (   INITIAL CONDITION
```

Figure 7.3. Listing of Model VI.

```
51A  SHA1.K=CLIP(SOUT1.K,SAVL1.K,CSD.K,50)  (   CL SIXTY HA ARR RATE 1 AUX 5
51A  SHA2.K=CLIP(SOUT2.K,SAVL2.K,CSD.K,50)  (   CL SIXTY HA ARR RATE 2 AUX 5
51A  SHA3.K=CLIP(SOUT3.K,SAVL3.K,CSD.K,50)  (   CL SIXTY HA ARR RATE 3 AUX 5
15   SHAR.K=SHA1.K+SHA2.K+SHA3.K            (   CL SIXTY HA ARRIVAL RATE
1L   CTMV1.K=CTMV1.J+(DT)(TDHR1.JK-THAR1.JK)  ( CL TWELVE MOVEMENT LEVEL 1
6N   CTMV1=0                                (   INITIAL CONDITION
1L   CTMV2.K=CTMV2.J+(DT)(TDHR2.JK-THAR2.JK)  ( CL TWELVE MOVEMENT LEVEL 2
6N   CTMV2=0                                (   INITIAL CONDITION
1L   CTMV3.K=CTMV3.J+(DT)(TDHR3.JK-THAR3.JK)  ( CL TWELVE MOVEMENT LEVEL 3
6N   CTMV3=0                                (   INITIAL CONDITION
4S   CTMV.K=CTMV1.K+CTMV2.K+CTMV3.K         (   CL TWELVE MOVEMENT LEVEL
39R  CTMR1.KL=DELAY3(TDHR1.JK,0.45)         (   CL TWELVE MOVEMENT RATE 1
39R  CTMR2.KL=DELAY3(TDHR2.JK,0.70)         (   CL TWELVE MOVEMENT RATE 2
39R  CTMR3.KL=DELAY3(TDHR3.JK,0.95)         (   CL TWELVE MOVEMENT RATE 3
4S   CTMR.K=CTMR1.JK+CTMR2.JK+CTMR3.JK          CL TWELVE MVMT RATE
12A  TAVL1.K=(20)(CTMV1.K)                  (   CL TWELVE MVMT AVAILABLE 1
12A  TAVL2.K=(20)(CTMV2.K)                  (   CL TWELVE MVMT AVAILABLE 2
12A  TAVL3.K=(20)(CTMV3.K)                  (   CL TWELVE MVMT AVAILABLE 3
6A   TOT1.K=CTMR1.JK                        (   CL TWELVE HA ARR RATE 1 AUX 2
6A   TOT2.K=CTMR2.JK                        (   CL TWELVE HA ARR RATE 2 AUX 2
6A   TOT3.K=CTMR3.JK                        (   CL TWELVE HA ARR RATE 3 AUX 2
14A  TOU1.K=(TOT1.K)NORMRN(1,0.25)          (   CL TWELVE HA ARR RATE 1 AUX 1
14A  TOU2.K=(TOT2.K)NORMRN(1,0.25)          (   CL TWELVE HA ARR RATE 2 AUX 1
14A  TOU3.K=(TOT3.K)NORMRN(1,0.25)          (   CL TWELVE HA ARR RATE 3 AUX 1
56A  TOUT1.K=MAX(TOU1.K,0)                  (   CL TWELVE HA ARR RATE 1 AUX 3
56A  TOUT2.K=MAX(TOU2.K,0)                  (   CL TWELVE HA ARR RATE 2 AUX 3
56A  TOUT3.K=MAX(TOU3.K,0)                  (   CL TWELVE HA ARR RATE 3 AUX 3
51R  THAR1.KL=CLIP(TOUT1.K,TAVL1.K,CTD.K,223) ( CL TWELVE HA ARR RATE 1
6N   THAR1=0                                (   INITIAL CONDITION
51R  THAR2.KL=CLIP(TOUT2.K,TAVL2.K,CTD.K,223) ( CL TWELVE HA ARR RATE 2
6N   THAR2=0                                (   INITIAL CONDITION
51R  THAR3.KL=CLIP(TOUT3.K,TAVL3.K,CTD.K,223) ( CL TWELVE HA ARR RATE 3
6N   THAR3=0                                (   INITIAL CONDITION
51A  THA1.K=CLIP(TOUT1.K,TAVL1.K,CTD.K,223)   ( CL TWELVE HA ARR RATE 1 AUX 5
51A  THA2.K=CLIP(TOUT2.K,TAVL2.K,CTD.K,223)   ( CL TWELVE HA ARR RATE 2 AUX 5
51A  THA3.K=CLIP(TOUT3.K,TAVL3.K,CTD.K,223)   ( CL TWELVE HA ARR RATE 3 AUX 5
5S   THAR.K=THA1.K+THA2.K+THA3.K            (   CL TWELVE HA ARRIVAL RATE
13A  ASDH.K=(ASCC.K)(1+SMDT.K)              (   CL SIXTY DEPLOYED TO HA AUX
51A  DUMY.K=CLIP(2.68,4.85,CTD.K,1351)      (   DUMMY VARIABLE
51A  RTTS.K=CLIP(2.35,DUMY.K,CTD.K,2076)    (   RATIO CL TWELVE TO CLASS SIXTY
12A  CSAV.K=(20)(CSD.K)                     (   SIXTY DEPLOYED TO HA AUX
54A  SDHR.K=MIN(CSAV.K,ASDH.K)              (   CL SIXTY DEPLOYED TO HA AUX
12R  SDHR1.KL=(0.25)(SDHR.K)                (   CL SIXTY DEPLOYED TO HA RATE 1
6N   SDHR1=0                                (   INITIAL CONDITION
12R  SDHR2.KL=(0.5)(SDHR.K)                 (   CL SIXTY DEPLOYED TO HA RATE 2
6N   SDHR2=0                                (   INITIAL CONDITION
12R  SDHR3.KL=(0.25)(SDHR.K)                (   CL SIXTY DEPLOYED TO HA RATE 3
6N   SDHR3=0                                (   INITIAL CONDITION
54A  ASDR.K=MIN(CSAV.K,ASDH.K)              (   CL SIXTY DEPLOYED HA RATE AUX
12A  AMR.K=(RTTS.K)(ASDR.K)                 (   ADJUSTED CL TWELVE MVMT RATE AU
51A  ATMR.K=CLIP(AMR.K,ATCC.K,CSD.K,45)     (   E
12A  CTAV.K=(20)(CTD.K)                     (   TWELVE DEPLOYED TO HA AUX
54A  TDHR.K=MIN(CTAV.K,ATMR.K)              (   CL 12 DEPLOYED TO HA RATE
12R  TDHR1.KL=(0.25)(TDHR.K)                (   CL TWELVE DEPLOYED TO HA RATE 1
6N   TDHR1=0                                (   INITIAL CONDITION
12R  TDHR2.KL=(0.5)(TDHR.K)                 (   CL TWELVE DEPLOYED TO HA RATE 2
6N   TDHR2=0                                (   INITIAL CONDITION
12R  TDHR3.KL=(0.25)(TDHR.K)                (   CL TWELVE DEPLOYED TO HA RATE 3
6N   TDHR3=0                                (   INITIAL CONDITION
52L  CSD.K=CSD.J+(DT)(0-SDHR1.JK-SDHR2.JK-SDHR3.JK) ( CL SIXTY VEH DEPLOYED
6N   CSD=1067                               (   INITIAL CONDITION
52L  CTD.K=CTD.J+(DT)(0-TDHR1.JK-TDHR2.JK-TDHR3.JK) ( CL TWELVE VEH DEPLOYED
6N   CTD=3189                               (   INITIAL CONDITION
1L   CSSC.K=CSSC.J+(DT)(ASCR.JK+0)          (   CL SIXTY VEH SUCCESS CROSSED
6N   CSSC=0                                 (   INITIAL CONDITION
1L   CTSC.K=CTSC.J+(DT)(ATCR.JK+0)          (   CL TWELVE VEH SUCCESS CROSSED
6N   CTSC=0                                 (   INITIAL CONDITION
48S  RSHC.K=CSHA.K/(ASCC.K+1)               (   SIXTY HA XING RATIO
48S  RTHC.K=CTHA.K/(ATCC.K+1)               (   TWELVE HA XING RATIO
48S  RSDC.K=CSID.K/(ASCC.K+1)               (   SIXTY DEFILE XING RATIO
48S  RTDC.K=CTID.K/(ATCC.K+1)               (   TWELVE DEFILE XING RATIO
40A  TCC.K=MSCR.K+(1/2)(MTCR.K+1)
20S  RDC.K=TVID.K/TCC.K                     (   RATIO DEFILE TO CC
20S  RHC.K=TVHA.K/TCC.K                     (   RATIO HA TO CROSSING CAP
47A  DCL.K=RAMP(TVID.K,4)                   )   DEFILE CONC LEVEL
47A  DCLN.K=RAMP(1,4)                       )   DEFILE CONC LEVEL N
48S  ATVID.K=DCL.K/(DCLN.K+0.0001)          )   CUM AVE VEH IN DEFILE
47A  HACL.K=RAMP(TVHA.K,4)                  )   HA CONC LEVEL
48S  ATVHA.K=HACL.K/(DCLN.K+0.0001)         )   CUM AVE VEH IN HA
47A  SDM.K=RAMP(SDT.K,0)                    )   SIXTY DOWN TIME LEVEL
47A  TDM.K=RAMP(TDT.K,0)                    )   TWELV DOWN TIME LEVEL
48S  ASDT.K=SDM.K/(CLOK.K+0.0001)           )   CUM AVE 60 DOWN TIME
48S  ATDT.K=TDM.K/(CLOK.K+0.0001)           )   CUM AVE 12 DOWN TIME
PRINT 1)SDT/2)TDT/3)TVID/4)TVHA/5)SHDR/6)THDR/7)SDHR/8)TDHR/9)SHAR
PRINT 1)RSHC/2)RTHC/3)RSDC/4)RTDC/5)CSSC/6)CTSC/7)CSC/8)CTD/9)CSMV
PRINT 1)RHC/2)RDC/3)CSHA/4)CTHA/5)ASCR/6)ATCR/7)TCOS/8)CTMV/9)THAR
PRINT 1)ATVID/2)ATVHA/3)ASDT/4)ATDT/5)CSMR/6)CTMR/7)SDEL
PRINT 1)BRIO/2)MARO/3)RFTO/4)LTRO/5)MSCR/6)MTCR
PLOT  CSSC=S(0,1400)/CTSC=T(0,3900)/ASCR=R/ATCR=P/TVID=C
PLOT  SMPT=A/SDT=G/TDT=I/SDEL=D(0,10)/TVHA=H/CSID=J/CTID=K
PLOT  BRIO=B/MARO=M/RFTO=E/LTRO=L/MSCR=U/MTCR=V/TCOS=Z
SPEC  DT=0.05/LENGTH=16/PRTPER=0.10/PLTPER=0.10
```

Figure 7.4. Listing of Model VI.

1L CLOK.K = CLOK.J + (DT) (1 + 0) Problem Time

6N CLOK = 0 Initial Condition

Similar equations were written for:

MARO	Mobile Assault Rafts in Operation
RFTO	M4T6 Rafts in Operation
LTRO	Light Tactical Rafts in Operation

Allowing for the possibility that some class 12 vehicles may cross on class 60 means, the maximum class 60 crossing capability and the minimum class 12 crossing capability are determined by the following equations:

17A MSCR.K = (400)(1)(BRIO.K)+(12)(1)(MARO.K)+(6)(1)(RFTO.K) Maximum Class 60 Crossing Capability

12A MTCR.K = (6) (LTRO.K) Minimum Class 12 Crossing Capability

In models II and III these crossing capabilities were altered on the basis of two assumptions (10, 11):

a. Use of the crossing means would on the average be accomplished with an efficiency of ninety per cent.

b. This efficiency of use would be normally distributed with a standard deviation of five per cent.

The normal distribution provided in Dynamo is truncated at 2.4 standard deviations (32), so that the two assumptions taken together state that the crossing means will be operated over an approximate normally distributed range from 78 to 102 per cent efficiency.

In Models IV, V and VI an entirely different approach was taken to determine the crossing capabilities. All three of these models made use of an added construction portion which is discussed in the following section.

The Addition of a Construction Portion

Crossing means came into operation in strict accordance with the crossing plan in the first three models. This seldom occurs in actual practice. The training status of construction crews will vary, the condition of bridging equipment is unlikely to be uniform, and the conditions under which the construction crews work will vary due to local differences in terrain and the enemy situation. We can more reasonably expect that the various crossing means will come into operation over a period of time, distributed in some way about the planned or expected time. Though data is available as to the efficiency of bridging and rafting operations (10, 11), no data could be obtained in regard to the actual behavior of construction times. Mean times were selected for each type equipment from prescribed construction rates (10, 11). The variances and distributions used in the model were selected by reflecting upon the field experiences of the author. Even with this limitation, the level of realism in the model's behavior has certainly been raised by adding a degree of uncertainty in regard to bridge and raft construction. On the foregoing basis 116 Dynamo equations were written to simulate the construction of crossing equipment. The equations are totally reflected in Figures 6 and 7.

By way of explanation the equations for the construction of bridges for plan E will be presented. The division staff will continuously monitor the raft and bridge construction status. Since delta time was set at three minutes in the model, it was decided to sample the construction status every six minutes, thereby providing for some small communication delay in the transmittal of this information. The equation which determines the number of bridges in operation is:

43A BRIO.K = SAMPLE (BRIN.K, 0.1) Bridges in Operation

The variable BRIN reflects the actual status of each bridge based on the following equations:

7A BRIN.K = BRIN1.K + BRIN2.K

51A BRIN1.K = CLIP (1, 0, BCS1.K, 1)

51A BRIN2.K = CLIP (1, 0, BCS2.K, 1)

where BCS1 and BCS2 reflect the per cent completion of the two bridges in plan E. The clip equation type in Dynamo is quite adaptable to a number of logic uses, and in a remote way resembles the IF statements of Fortran or Algol. In this example BRIN1 is set equal to 1 if BCS1 is greater than or equal to 1; otherwise it is set equal to zero. The memory required for updating BCS1 and BCS2 is easily obtained through the use of a Dynamo ramp function as reflected in the following equations:

47A BCS1.K = RAMP (BCR1.K, 2.5)

47A BCS2.K = RAMP (BCR2.K, 2.5)

where BCR1 and BCR2 represent the probabilistic construction rates for a M4T6 bridge and a mobile assault bridge respectively. The equations used for BCR1 and BCR2 were:

34A BCR1.K = (1) NORMRN (0.25, 0.05)

34A BCR2.K = (1) NORMRN (0.67, 0.12)

These equations result in normally distributed construction rates which are truncated at 2.4 standard deviations as mentioned in the previous section (32).

Similar equations were written for the construction of the various type rafts. The greatest gain from this approach is the added uncertainty of construction which is an important factor in the prediction of crossing capability that occurs in Models V and VI.

Maintaining Tactical Integrity

Because of the differing load capabilities of crossing equipment the Dynamo models were structured to consider vehicles in two classes. The two classes were vehicles greater than class 12, and those which were equal to or less than class 12. It was therefore vital that the simulation programs also insure that the tactical integrity of units not be lost due to this necessary structural approach. This was done quite easily in simulating the movement of units from deployed positions through holding areas and into the crossing areas. This part of maintaining tactical integrity will be explained later during the discussion of movement rates.

Within the crossing areas a more difficult problem occurs. It is not only a problem associated with model structure, but also one of tactical doctrine that is significant to effective defile control. From previous discussion it is readily seen that the division's class 60 crossing capability far exceeds its class 12 crossing capability. Since there are 3389 vehicles of class 12 and less in the division compared to 1109 vehicles greater than class 12, a substantial number of the lower class vehicles must cross on class 60 means; this number will vary with time according to the tactical plan. The doctrinal considerations will be discussed in Chapter VI. However, these considerations can not be fully ignored here, if a realistic simulation is to result. Briefly then, vehicles arrive within crossing areas as part of tactical units. Within any unit the times to cross each class of vehicles must be approximately equal in order for unit integrity to be maintained, and for crossing means downtime not to result. For simulation purposes the division was segmented into three echelons according to the tactical plan (4). Echelon A consisted of the assault brigades along with their direct support artillery and logistical combat trains. Echelon B consisted of the division's reserve brigade and the remainder of the division's artillery minus its Honest John missile battalion. Echelon C was comprised of the remainder of the division. For each of these echelons the ratio of class 12 to class 60 vehicles was determined as reflected in Table 5. This ratio is hereafter referred to as the tactical plan parameter. Whatever crossing plan is being used can also be described in terms of a parameter α whose value is dependent on the crossing means in operation at the time. The vehicle crossing rate on bridges is approximately identical for all classes of vehicles, but the vehicle crossing rate for class 60 rafts is dependent upon the vehicles being transported. Vehicle size rather than weight is the

Table 5. Ratio of Class 12 to Class 60 Vehicles

Echelon	Ratio of Class 12 to Class 60
A	2.35:1
B	2.68:1
C	4.85:1

governing criterion, and an accepted rule of thumb is that two vehicles less than class 12 can be rafted in place of one vehicle greater than class 12 (4, 10, 11). Assuming that all class 60 means will be made available to class 12 vehicles on a proportionate basis, and letting α represent the crossing plan parameter, it is determined that:

$$\alpha = \frac{r + b}{2r + b}$$

where r is the class 60 rafting capability, and b is the class 60 bridging capability. With the tactical and crossing plan parameters determined, the following relationships were developed:

Let	x = MSCR	Maximum Class 60 Crossing Capability
	y = MTCR	Minimum Class 12 Crossing Capability
	u = ASCC	Actual Class 60 Crossing Capability
	v = ATCC	Actual Class 12 Crossing Capability

z	=	TCS	Class 12 Vehicles Crossing on Class 60 Means
α	=	XCP	Crossing Plan Parameter
β	=	XRTS	Tactical Plan Parameter

Three linear equations can be written:

$$\beta u - v = 0 \qquad (1)$$

$$u + \alpha z = x \qquad (2)$$

$$v - z = y \qquad (3)$$

Eliminating u and v from this set of equations, and solving for z in terms of x, y, α and β, yields:

$$z = \frac{\beta x - y}{1 + \alpha\beta} \qquad (4)$$

From Table 5 and equation 4 the following Dynamo equations were written:

51A XDUM.K = CLIP (2.68, 2.35, CTSC.K, 1313) Dummy Variable

51A XRTS.K = CLIP(4.85, XDUM.K, CTSC.K, 2038)Tactical Plan Parameter

where CTSC is the number of class 12 vehicles successfully crossed.

15A DA1.K = (BRIO.K) (400) + (RFTO.K) (12)

14A DA2.K = 0.0001* + (MARO.K) (24)

\- - - - - - -

*Added to avoid division by zero.

48A XCP. K = AMSCR. K/ (DA1. K + DA2. K) Crossing Plan Parameter

14A DTCS. K = 1 + (XCP. K) (XRTS. K)

14A NTCS. K = -MTCR. K + (XRTS. K) (MSCR. K)

20A TCS. K = NTCS. K/DTCS. K

56A TCOS. K* = MAX (TCS. K, 0) Class 12 Vehicles Crossing on Class 60 Means

Actual Crossing Capabilities and Rates

Actual crossing capabilities can now be determined based on the MSCR, MTCR and TCOS values at any time K. The actual rates will equal the capabilities, provided the forward movement of units have been timely compared to crossing capabilities. The following set of equations easily result:

14A ASCC. K = MSCR. K+(TCOS. K)(-XCP. K) Actual Class 60 Crossing Capability

7A ATCA. K = MTCR. K + TCOS. K

14A ATCB. K = MTCR. K + (1. 1) (MSCR. K)

51A ATCC. K = CLIP (ATCB. K, ATCA. K, CSSC. K, 1108) Actual Class 12 Crossing Capability

The last equation simply turns all crossing means over to class 12 vehicles near the crossing's end when all class 60 vehicles have been successfully crossed. Since delta time is set equal to 0. 05 hours, the number of vehicles available within the defiles is determined as follows:

- - - - - - -

*Sets this variable equal to zero when TCS is computed to be negative.

12A SVEH.K = (20) (CSID.K) Class 60 Vehicles Available

12A TVEH.K = (20) (CTID.K) Class 12 Vehicles Available

where CSID and CTID represent the number of vehicles by class present within the defiles. The actual crossing rates at any time are, therefore:

54R ASCR.KL = MIN (ASCC.K, SVEH.K) Actual Class 60 Crossing Rate

54R ATCR.KL = MIN (ATCC.K, TVEH.K) Actual Class 12 Crossing Rate

The utilization of crossing means can now be determined. However, to overcome a technicality in Dynamo which requires that rates for the previous delta time be used when needed as independent variables in other Dynamo equations, the following auxiliary equations were written:

54A SCR.K = MIN (ASCC.K, SVEH.K)

54A TCR.K = MIN (ATCC.K, TVEH.K)

The equations for the per cent non-utilization of available crossing means are, therefore:

26A SDT.K = (ASCC.K - SCR.K + 0)/(ASCC.K + 1 + 0) Sixty Downtime

26A TDT.K = (ATCC.K- TCR.K+ 0)/(ATCC.K+ 1 + 0) Twelve Downtime

These non-utilization figures are a measure of the effectiveness of the simulated defile control. Therefore, when downtime on crossing means does occur these variables are used to correct forward movement rates accordingly. An explanation of this fact is provided in the following section.

Prediction of Crossing Capability

The investigation of defile control measures must certainly include an examination of when an increase in crossing capability should be predicted. The timeliness and accuracy of this prediction will bear considerably on controlling effectively the forward movement of the division's units. Consequently, the predictive portion was programmed so that the occurrence in time of this predictive could be easily changed during successive runs of the simulation. Only the structure of this portion will be discussed in this section. Subsequent discussions in this chapter and the following chapter will deal with the method of procedure for the investigation of this factor.

An extract of the listing from Models V and VI is reflected in Figure 8 to facilitate explanation of this portion of the model. CSCP, the class 60 crossing predictor is simply the algebraic sum of the three predictors for M4T6 Rafts (RP). Each of these predictors is equated to zero or to an increased movement rate depending on whether or not the specific crossing means construction status is less than the established decision criteria for that particular crossing means. An additional auxiliary equation resets the predictor to zero when the construction status reaches a value of 1, since forward movement thereafter will be based on the crossing means which are actually in operation. For example, consider the equations which relate to M4T6 rafts:

10A	RCS1.K	=	AS.K + BS.K + CS.K + DS.K + ES.K + FS.K	
11A	RCS2.K	=	GS.K + HS.K + IS.K + JS.K + KS.K + LS.K + MS.K + NS.K	
21A	RCS.K	=	(1/14) (RCS1.K + RCS2.K)	Raft Construction Status

8A	CSCP. K = BP. K + MBP. K + RP. K	Class Sixty Crossing Predictor
51A	BP. K = CLIP (0, BPD. K, BCS1. K, 1)	Bridge Predictor
C	BDC1 = 0, 75	Bridge Decision Criteria
51A	BPD. K = CLIP (IMR1. K, 0, BCS1. K, BDC. K)	Dummy Variable
7A	MSC. K = AMSCR. K + 0. 0001	
40A	IMR1. K = -1+(1/MSC. K) (AMSCR. K+ 400)	Increased Movement Rate 1
51A	MBP. K = CLIP (0, MBPD. K, BCS2. K, 1)	Mobile Bridge Predictor
51A	MBPD. K = CLIP (IMR1. K, 0, BCS2. K, BDC2. K)	Dummy Variable
C	BDC2 = 0. 33	Mobile Bridge Decision Criteria
10A	RCS1. K = AS. K + BS. K + CS. K + DS. K + EE. K + FS. K	
11A	RCS2. K = GS. K + HS. K + IS. K + JS. K + KS. K + LS. K + MS. K + NS. K	
21A	RCS. K = (1/14) (RCS1. K + RCS2. K)	Raft Construction Status
51A	RP. K = CLIP (0, RPD. K, RCS. K, 1)	Raft Prediction
C	RDX = 0. 33	Raft Decision Criteria
51A	RPD. K = CLIP (IMR2. K, 0, RCS. K, RDX. K)	Dummy Variable
40A	IMR2. K = -1 + (1/MSC. K) (AMSCR. K + 84)	Increased Movement Rate
43A	SMPT. K = SAMPLE (CSCP. K, 0. 2)	Sixty Means Predicted Time
56A	SMDT. K = MAX(SDT. K, SMPT. K)	Sixty Means Downtime Aux

Figure 8. Crossing Means Predictive Portion

where RCS2. K and RCS. 2K simply sum the status of individual rafts.

51A	RP. K = CLIP (0, RPD. K, RCS. K, 1)	Raft Predictors
51A	RPD. K = CLIP (IMR2. K, 0, RCS. K, RDX. K)	Dummy Variable
C	RDX = 0. 33	Raft Decision Criteria
40A	IMR2. K = -1 + (1/MSC. K) (AMSCR. K + 84)	Increased Movement Rate 2

where to avoid division by zero, we have the equation:

7A MSC. K = AMSCR. K + 0. 0001

by setting RDX = 0. 33 in the case of M4T6 rafts, the model is predicting that these 14 rafts will come into operation in one hour, since the overall construction time is estimated at 90 minutes. IMR2 simply predicts what percentage of non-utilization of crossing capability will result if no increased forward movement of units takes place.

Recalling that,

8A CSCP. K = BP. K + MBP. K + RP. K Class Sixty Crossing Prediction

and allowing three to nine minutes to communicate movement orders and for units to begin moving, sixty means predicted time is expressed as follows:

43A SMPT. K = SAMPLE (CSCP. K, 0. 2) Sixty Means Predicted Time

and further recalling from the previous section that actual downtime should also result in increased movement, the following equation was written:

56A SMDT.K = MAX (SDT.K, SMPT.K)

It is the variable SMDT that actually signals increased movement to the movement portion of the model. The communicative equation is:

18A ASDH.K = (ASCC.K) (1 + SMDT.K)

where ASDH is the auxiliary class 60 deployed to holding area rate and ASCC is the actual class 60 crossing capability.

Measures of Troop Concentration

Our concern lies in three areas. These are with units moving from deployed positions to holding areas, units actually occupying holding areas and units within the actual crossing areas. The discussion of acceptable levels of troop concentration will be reserved for a section of Chapter V. Each of these measures is the dependent variable of a Dynamo level equation, so in addition to these equations all of the model's level equations will be discussed in this section.

The equations for class 12 and class 60 vehicles are similar throughout the model. Therefore only the class 60 equations will be presented. Beginning with the units in a deployed position we have the following set of equations:

52L CSD.K = CSD.J + (DT)(0-SDHR1.JK - SDHR2.JK - SDHR3.JK) Class Sixty Vehicles Deployed

6N CSD = 1067 Initial Condition

where SDHRi represents the ith rate of movement from deployed positions to holding areas. More than one rate of movement was used to simulate differing distances and road conditions between deployed positions and holding areas. This point will be further discussed in the subsequent section on movement rates. The units actually moving from deployed positions to holding areas are represented as follows:

1L	CSMV1.K =CSMV1.J+(DT)(SDHR1.JK-SHAR1.JK)	Class Sixty Movement Level 1
6N	CSMV1 = 0	Initial Condition
1L	CSMV2.K=CSMV2.J+(DT)(SDHR2.JK-SHAR2.JK)	Class Sixty Movement Level 2
6N	CSMV2 = 0	Initial Condition
1L	CSMV3.K=CSMV3.J+(DT)(SDHR3.JK-SHAR3.JK)	Class Sixty Movement Level 3
6N	CSMV3 = 0	Initial Condition
8S	CSMV.K = CSMV1.K+CSMV2.K+CSMV3.K	Class Sixty Movement Level

where SHARi represents the ith holding area arrival rate for class 60 vehicles. The level of concentration in holding areas is determined by the following equations:

52L	CSHA.K = CSHA.J+(DT)(SHAR1.JK+SHAR2.JK+SHAR3.JK-SHDR.JK)	Class Sixty Vehicles in Holding Areas
6N	CSHA = 42	Initial Condition

where SHDR represents the class 60 holding area to defile rate. The concentration of vehicles within the defile is determined as follows:

1L CSID.K = CSID.J+(DT)(SHDR.JK-ASCR.JK) Class Sixty Vehicles in Defile

6N CSID = 0 Initial Condition

where ASCR is the actual class 60 crossing rate. The number of class 60 vehicles successfully crossed is determined by the following equations:

1L CSSC.K = CSSC.J +(DT)(ASCR.JK+0) Class Sixty Vehicles Successfully Crossed

6N CSSC = 0 Initial Condition

This concludes presentation of the model's class 60 levels. The model does provide a number of auxiliary variables which relate to troop concentration. These will be discussed in subsequent sections.

Movement Rates

As previously mentioned the maintaining of unit integrity throughout the model is vital to attaining a realistic simulation. It was, therefore, decided to make the flow of one class of vehicle entirely dependent upon the flow of the other. Class 60 vehicle flow was selected as the independent flow, though certainly the selection of class 12 flow would have worked equally as well.

In the discussion of predicting crossing capability the equation was given for ASDH, the auxiliary class 60 deployed to holding area rate. This equation will serve as a logical point of departure for a discussion of movement rates. Recalling that:

18A ASDH.K = (ASCC.K) (1 + SMDT.K)

This variable will be the aggregate class 60 deployed to holding area rate provided sufficient class 60 vehicles are still deployed to fulfil that rate. Since delta time is 0.05 hours we can write the following equations:

12A CSAV.K = (20) (CSD.K) Class Sixty Vehicles Available

54A SDHR.K = (MIN (CSAV.K, ASDH.K)Class Sixty Deployed to Holding Area Rate

It should be noted that SDHR is expressed as an auxiliary variable rather than as a rate. This is because not all units will encounter the same movement time to holding area due to varying distances and road conditions from their deployed locations. Based on the particular tactical situation (4), it was determined that one fourth of the units would encounter an average movement time of thirty minutes, and one half of the units would encounter an average movement time of forty-five minutes, and the remaining units would require an average movement time of one hour. This determination is somewhat aggregated. If greater refinement had been desired more equations could have been written. If the proportion of units associated with the average movement times would vary during the conduct of the crossing this could also be modeled. These proportions would then be stated as variables dependent on some other variable within the model. It will be recalled that the tactical plan parameter was handled in this manner. To accommodate the differing movement times the following equations were written based on the value of SDHR:

12R SDHR1.KL = (0.25) (SDHR.K)

12R SDHR2.KL = (0.5) (SDHR.K)

12R SDHR3.KL = (0.25) (SDHR.K)

The dependent class 12 deployed to holding area rates were modeled with a similar set of equations. Based on the information contained in Table 5 on page 58 the following two equations were written:

51A	DUMY.K = CLIP (2.68, 4.85, CTD.K, 1351)	Dummy Variable
51A	RTTS.K = CLIP (2.35, DUMY.K, CTD.K, 2076)	Ratio Class Twelve to Class Sixty

where CTD is number of class 12 vehicles deployed. From this point the class 12 rates were determined as reflected in Figure 9.

The holding area arrival rates are, of course, dependent upon the departure rates from deployed positions and the average movement time required. Several different type of delay functions are available in Dynamo. The nature of the delay caused by the movement of march columns from one location to another is that initially there is no response to an increased rate of movement. Then, depending upon the length of the delay, the response will rise at an increasing rate until the new arrival rate is attained. For this reason the Dynamo third order exponential delay was selected to model the movement time of units from their deployed locations to holding areas. An extract of that portion of the model listing for class 60 vehicles is reflected in Figure 10. The class 12 movement portion is similar to the class 60 portion and is contained in Figures 6 and 7.

The movement rate from holding areas into the defiles is of course an

54A	ASDR.K = MIN(CSAV.K, ASDH.K)	Cl Sixty Deployed HA Rate Aux
12A	AMR.K = (RTTS.K) (ASDR.K)	Adjusted Cl Twelve Mvmt Rate Au
51A	ATMR.K+CLIP(AMR.K,ATCC.K,CSD.K,45)	E Dummy
12A	CTAV.K = (20) (CTD.K)	Twelve Deployed to HA Aux
54A	TDHR.K = MIN (CTAV.K,ATMR.K)	Cl Twelve Deployed to HA Rate
12R	TDHR1.KL = (0.25) (TDHR.K)	Cl Twelve Deployed to HA Rate 1
6N	TDHR1 = 0	Initial Condition
12R	TDHR2.KL = (0.5) (TDHR.K)	Cl Twelve Deployed to HA Rate 2
6N	TDHR2 = 0	Initial Condition
12R	TDHR3.KL = (0.35) (TDHR.K)	Cl Twelve Deployed to HA Rate 3
6N	TDHR3 = 0	Initial Condition

Figure 9. Class Twelve Deployed to Holding Area Rates

8S	CSMV.K=CSMV1.K+CSMV2.K+CSMV3.K	Cl Sixty Movement Level
12A	SAVL1.K=(20)(CSMV1.K)	Cl Sixty Mvmt Available 1
12A	SAVL2.K=(20)(CSMV2.K)	Cl Sixty Mvmt Available 2
12A	SAVL3.K=(20)(CSMV3.K)	Cl Sixty Mvmt Available 3
39R	CSMR1.KL=DELAY3(SDHR1.JK, 0.45)	Cl Sixty Movement Rate 1
39R	CSMR2.KL=DELAY3(SDHR2.JK, 0.70)	Cl Sixty Movement Rate 2
39R	CSMR3.KL=DELAY 3(SDHR3.JK, 0.95)	Cl Sixty Movement Rate 3
8S	CSMR.K=CSMR1.JK+CSMR2.JK+CSMRs.JK	Cl Sixty Movement Rate
6A	SOT1.K=CSMR1.JK	Cl Sixty HA Arr Rate 1 Aux 1
6A	SOT2.K=CSMR2.JK	Cl Sixty HA Arr Rate 2 Aux 1
6A	SOT3.K=CSMR3.JK	Cl Sixty HA Arr Rate 3 Aux 1
34A	SOU1.K=(SOT1.K) NORMRN(1.0.25)	Cl Sixty HA Arr Rate 1 Aux 2
34A	SOU2.K=(SOT2.K)NORMRN(1, 0.25)	Cl Sixty HA Arr Rate 2
34A	SOU3.K=(SOT3.K)NORMRN(1, 0.25)	Cl Sixty HA Arr Rate 3
56A	SOUT1.K=MAX(SCU1.K, 0)	Cl Sixty HA Arr Rate 1 Aux 3
56A	SOUT2.K=MAX(SOU2.K, 0)	Cl Sixty HA Arr Rate 2 Aux 3
56A	SOUT3.K=MAX(SOU3.K, 0)	Cl Sixty HA Arr Rate 3 Aux 3
51R	SHAR1.KL=CLIP(SOUT1.K, SAVL1.K, CSD.K, 50)	Cl Sixty HA Arrival Rate 1
6N	SHAR1=0	Initial Condition
51R	SHAR2.KL=CLIP(SOUT2.K, CSD.D, 50)	Cl Sixty HA Arrival Rate 2
6N	SHAR2=0	Initial Condition
51R	SHAR3.KL=CLIP(SOUT3.K, SAVL3.K, CSD.K, 50)	Cl Sixty HA Arrival Rate 3
6N	SHAR3=0	Initial Condition
51A	SHA1.K=CLIP(SOUT1.K, SAVL1.K, CSD.K, 50)	Cl Sixty HA Arr Rate 1 Aux 5
51A	SHA2.K=CLIP(SOUT2.K, SAVL2.K, CSD.K, 50)	Cl Sixty HA Arr Rate 2 Aux 5
51A	SHA3.K=CLIP(SOUT3.K, SAVL3.K, CSD.K, 50)	Cl Sixty HA Arr Rate 3 Aux 5
8S	SHAR.K=SHA1.K+SHA2.K+SHA3.K	Cl Sixty HA Arrival Rate

Figure 10. Class Sixty Movement Portion

important variable of interest associated with effective defile control. Units can be dispersed in holding areas which will greatly reduce their vulnerability to enemy fire. Once in the defile a unit's capability to disperse is markedly reduced. Therefore, the level of troop concentration to be allowed within the crossing area is one of the variables requiring investigation. Consequently, the defile portion was programmed so that this allowed level could be easily changed during successive runs of the simulation. The holding area delay should be established so that when the allowed level is being maintained units will move into the defile at a rate equal to the crossing capability. If the level is too high the forward movement rate should be severely reduced until the desired level is attained. If the level is too low, units should be moved forward as rapidly as possible within the bounds of the tactical situation under study (4). This holding area to defile portion is reflected in Figure 11. The common exponential function was selected as one which would reasonably represent the desired delay. From the tactical situation it was determined that the minimum movement time from holding areas into the defile was six minutes. The following basic relationship was established.

Let	y = ASDEL	The Desired Delay
	x = CSDC	A Measure of Defile Congestion
	z = CSID/ASCC	The Ratio of Class Sixty Vehicles in the Defile to Actual Crossing Capability
then	$y = 0.1e^{x}$	

The attainable minimum delay of six minutes is established by this equation. A

C	XY=9.2	Fifteen Min Level in Defile
50A	CSDC.K=(XY.K)(CSID.K)/(ASCC.K+0.0001)	Cl Sixty Defile Control
54A	CSDB.K=MIN(CSDC.K, 87)	Cl Sixty Defile C Aux
28A	ASDEL.K=(0.1)EXP(CSDB.K)	Class Sixty Delay
34A	SDEL.K=(ASDEL.K)NORMRN(1, 0.04)	Class Sixty Delay
20A	SHR.K=CSHA.K/SDEL.K	Sixty HA to Defile Aux
51A	SDUM.K=CLIP(ASCC.K, SHR.K, CSSC.K, 903)	Sixty Dummy
7A	SVAL.K=CSSC.K+CSID.K	Sixty Crossed Plus Defile
51A	SHRA.K=CLIP(0, SDUM.K, SVAL.K, 1109)	Sixty HA to Defile Aux 2
12A	SHAV.K=(20)(CSHA.K)	Sixty HA Available
54R	SHDR.KL=MIN(SHRA.K, SHAV.K)	Sixty HA to Defile Rate
6N	SHDR=0	Initial Condition
47A	CTMS.K=RAMP(THDR.JK, 0)	Cl Twelve Movement Status
51A	DUM.K=CLIP(2.68, 2.35, CTMS.K, 1313)	Dummy Variable
51A	RTS.K=CLIP(4.85, DUM.K, CTMS.K, 2038)	Ratio Twelve to Sixty
54A	ASHR.K=MIN(SHRA.K, SHAV.K)	Cl Sixty HA Rate Aux
12A	THR.K=(RTS.K)(ASHR.K)	Cl 12 HA TC Defile Rate Aux
47A	CSMX.K=RAMP(SHDR.JK, 0)	Cl 60 Movement Status
51A	TDUM.K=CLIP(ATCC.K, THR.K, CSMX.K, 1065)	E Dummy
7A	TVAL.K=CTSC.K+CTID.K	Twelve Crossed Plus Defile
51A	THRA.K=CLIP(0, TDUM.K, TVAL.K, 3389)	Cl Twelve HA Rate Aux
12A	THAV.K=(20)(CTHA.K)	Twelve HA Available
54R	THDR.KL=MIN(THRA.K, THAV.K)	Twelve HA to Defile Rate

Figure 11. Holding Area to Defile Portion

very large delay is also easily realized for any sizeable value of x. Now suppose that a fifteen minute level is to be allowed in the defile and that it is presently being maintained. The ratio of class sixty vehicles in the defile to the crossing capability must therefore be equal to 0.25 and the desired movement rate would equal the actual crossing capability. The Dynamo first-order exponential delay was selected as the model due to its more rapid response to a desired change. The desired delay is thereby determined to be one hour. Therefore,

$$e^x = 10$$

$$x = \ln 10 = 2.3$$

and

$$x = 9.2z$$

The parameter associated with the variable z, which represents a fifteen minute level in the defile has now been determined to be 9.2. For the case of a fifteen minute level in the defile y is plotted against z in Figure 12.

Unpredicted Outages of Crossing Means

Once crossing means come into operation they remain in service with a probability less than one. The causes for this are several. Operator error can cause a raft to be run aground, crossing equipment can require unexpected maintenance during operation and the enemy will direct whatever effort he is able against our crossing means. No unclassified published data could be found on the availability of crossing means during the conduct of actual assault river crossings. However, the effect of unexpected outages upon defile control measures can still

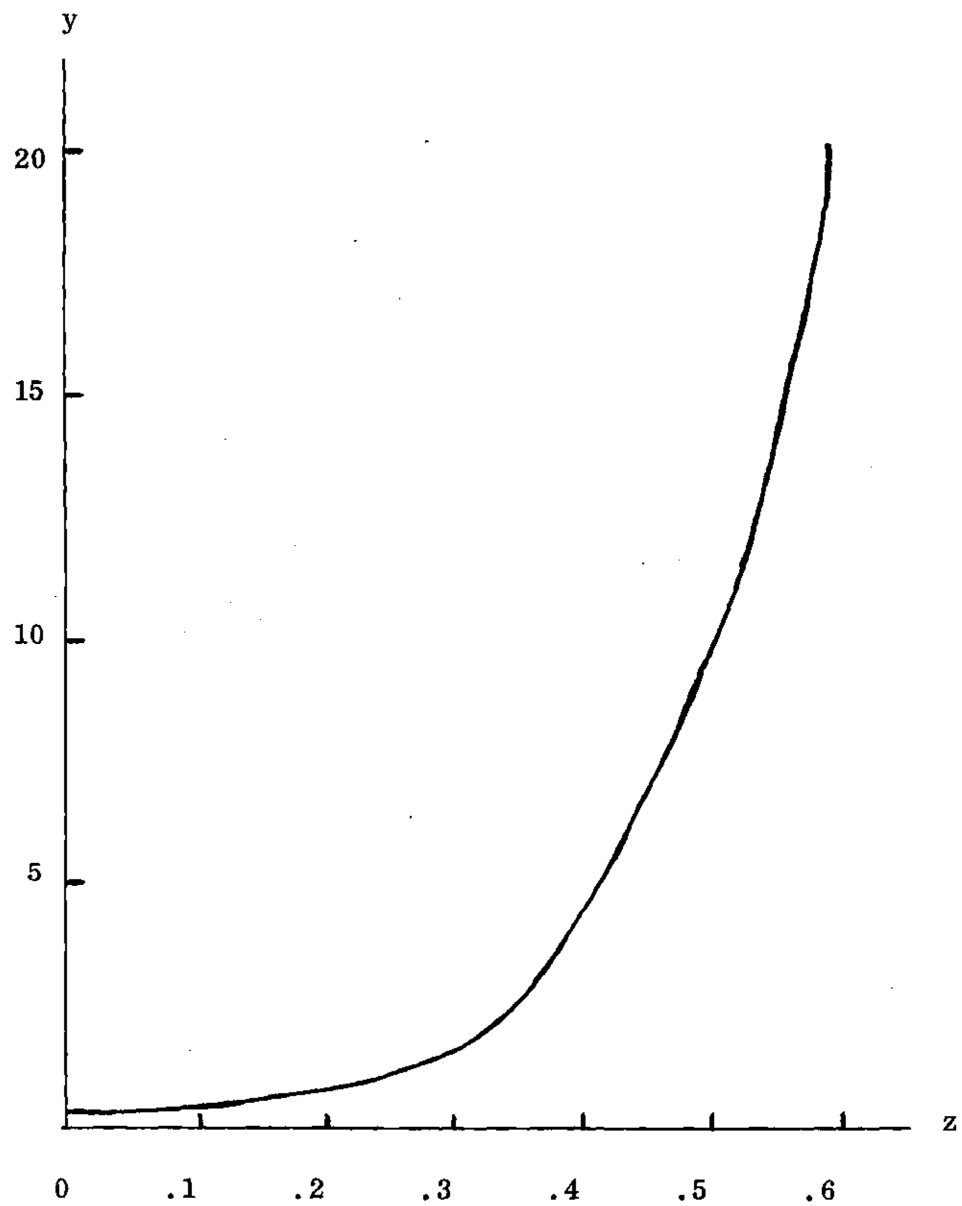

Figure 12. Holding Area Delay versus Defile Congestion

be studied by hypothetically establishing distribution functions for crossing means reliability and restoration to service. The reliability of crossing means was assumed to be binomially distributed* and repair rates were assumed to be normally distributed. The reliability function for the ith type of crossing equipment is therefore:

$$f_i(x_j) = \binom{n_i}{x_j} p_i^{\,x_j} \; q_i^{\,n_i - x_j}$$

$$\text{where } i = 1, 2, 3, 4$$

$$x_j = 0, 1, 2, \ldots . n_i$$

The values of p_i and n_i are reflected in Table 6.

Table 6. Reliability of Crossing Means

Type Equipment	p_i	n_i
Bridges	0.90	1 or 2**
Mobile Assault Rafts	0.96	4
M4T6 Rafts	0.90	14
Light Tactical Rafts	0.95	14

The mean repair time and associated variance were established for each

- - - - - - -

* Assuming independence of raft failures.

** Dependent upon crossing plan.

type of crossing equipment. From here the number of crossing means in operation were sampled for each type of crossing equipment at variable sample intervals distributed about the mean repair times. For example the equations for bridges in operation were:

43A BRIO.K = SAMPLE (BRINA.K, 0.1) Bridges in Operation

54A BRINA.K = MIN (BRIN.K, BROUT.K)

where BRIN is the same variable discussed in the section on the construction portion (page 55) and,

43A BROUT.K = SAMPLE (BROUT.K, BRR.K)

34A BRR.K = (1) NORMRN (1, 0.4) Bridge Repair Rate

51A BROT.K = CLIP (2, BROT1.K, RN.K, 0.19)

51A BROT1.K = CLIP (1, 0, RN.K, 0.01)

7A RN.K = RNA.K + 0.5 Uniformly Distributed Random Numbers on the 0-1 Interval

A similar set of equations were written for each type of crossing equipment. These are totally reflected in Figure 7.

Measures of Effective Defile Control

The non-utilization percentage of crossing means and the levels of troop concentration discussed in previous sections are measures of the effectiveness of the division's defile control measures. The time varying behavior of these variables would certainly be useful in any analysis of a defile control policy. However, other information would also be useful. The ratio of troop levels to the crossing capability and mean values of certain variables over the simulation span would also be valuable information. The programming of each model therefore included a number of such information variables.

The following ratios were programmed:

48S	RSHC.K = CSHA.K/ (ASCC.K + 1)	Sixty HA Crossing Ratio
48S	RTHC.K = CTHA.K / (ATCC.K + 1)	Twelve HA Crossing Ratio
48S	RSDC.K = CSTD.K/ (ASCC.K + 1)	Sixty Defile Crossing Ratio
48S	RTDC.K = CTID.K/ (ATCC.K + 1)	Twelve Defile Crossing Ratio
20S	RDC.K = TVID.K / TCC.K	Ratio Defile to Crossing Cap.
20S	RHC.K = TVHA.K/ TCC.K	Ratio HA to Crossing Capability

where TCC is the total crossing capability. In addition, the cumulative average concentration levels from the expected time of the first bridge coming into operation and the cumulative average crossing means downtimes were also programmed. These are extracted from the model for crossing plan B in Figure 13.

An Experiment

Two significant variables in an effective defile control policy are the time at which forward movement rates are increased in anticipation of increased crossing capability and the allowed level of vehicles within the defile at any time. The longer the division engineer waits to make his prediction the more accurate it will be. However, his prediction must be made in sufficient time for units to react

47A	DCL.K = RAMP (TVID.K, 6.5)	Defile Conc Level
47A	DCLN.K = RAMP (1, 6.5)	Defile Conc Level N
48S	ATVID.K = DCL.K/(DCLN.K+0.0001)	Cum Ave Veh in Defile
47A	HACL.K = RAMP (TVHA.K, 6.5)	HA Conc Level
48S	ATVHA.K = HACK.K/(DCLN.K + 0.0001)	Cum Ave Veh in HA
47A	SDM.K = RAMP (SDT.K, 0)	Sixty Downtime Level
47A	TDM.K = RAMP (TDT.K, 0)	Twelve Downtime Level
48S	ASDT.K = SDM.K / (CLOK.K+0.0001)	Cum Ave Sixty Downtime
48S	ATDT.K = IDM.K/ (CLOK.K+0.0001)	Cum Ave Twelve Downtime

Figure 13. Measures of Effective Defile Control

and move from their deployed positions into the holding areas. The span of average movement times in this situation was from 30 to 60 minutes (4). The same span of time was chosen for prospective prediction criteria. The level of vehicles in the defile should be as low as possible without resulting in significant downtime. Since the minimum delay time from holding areas to the defile was six minutes, the allowable defile level must exceed this to some degree. Consequently, defile levels of 7.5, 11.25 and 15 minutes were chosen. Establishing the predictive time levels at 30, 45 and 60 minutes a two factor three level experiment was decided for Models V and VI. Crossing plans B and E were chosen for the experiment,*

*The reasons for this choice are discussed in the first section of the next chapter.

so a total of thirty-six computer runs were necessary to conduct the experiment. Four additional runs of Model VI were made changing the random number seed, so that the results of differing random outage models could be compared.

CHAPTER V

THE SIMULATION RESULTS AND THEIR ANALYSIS

Comparison of Crossing Plans

Model I which was purely deterministic in structure was used for the comparison of crossing plans. The coming into operation of crossing means, and the prediction of increased crossing capability were input data to the computer routine. Since there was no uncertainty associated with these factors, Model I provided an unbiased comparison of crossing plans with no consideration being given to operational uncertainty.

The comparative results, reflected in Table 7, are startling. Considering only the first four plans, which do not involve breaking down the mobile assault rafts and swimming them together to form a bridge early in the crossing, only plan B is acceptable. Plan A takes too long to cross the entire division and plans C and D cross insufficient tanks and other needed class 60 vehicles in the first six hours of the crossing. Though not a doctrinal concept of the U. S. Army, there is much to recommend plan E. The plan certainly requires well trained engineers for successful execution, but the results are definitely rewarding. Plan E surprisingly optimizes the seemingly conflicting requirements. Nearly twice the required number of class 60 vehicles are across the river by K + 6 hours and the entire division is crossed in the least time. This realization of

Table 7. Comparison of Crossing Plans, Model I

Plan	Class 60 Vehicles Crossed at K + 6	Time Division Crossing Completed (Hours)
A	400	15.4
B	288	11.4
C	229	10.0
D	169	9.3
E	463	8.9

conflicting goals is the reward any commander can gain from one early bridge.

In the subsequent models only crossing plans B and E were investigated; the other plans having been rejected as unacceptable, based upon the results of simulation with Model I. A comparison of crossing plans B and E from the various runs of Models V and VI is reflected in Table 8. It can be seen that both crossing plans meet the criteria stated in Chapter III for crossing a minimum of 260 class 60 vehicles by K + 6 hours, and for crossing the entire division in no more than 14 hours. However, plan E meets the stated criteria by a considerable margin, whereas plan B does not.

Acceptable Levels of Troop Concentration

The determination of the levels of troop concentration which can be considered acceptable in a particular tactical situation is a matter of considerable consequence in the development of tactical doctrine. Though much of the pertinent information in this area is classified, especially since the advent of tactical

Table 8. Comparison of Crossing Plans, Models V and VI

Plan and Model	Class 60 Vehicles Crossed at K + 6*	Time Division Crossing Completed* (Hours)
B-V	278	11.9
E-V	437	9.5
B-VI	269	12.2
E-VI	420	10.1

nuclear weapons (12), an approach to this problem may still be taken in an unclassified vein. For instructional purposes in the employment of nuclear weapons, the U. S. Army has developed a hypothetical family of tactical nuclear weapons. The detailed effects data of these weapons is available in FM 101-31-3, Staff Officers Field Manual, Nuclear Weapons Employment (12).

The method of procedure will be to take the pertinent data from FM101-31-3 in regard to the radii of damage for various hypothetical weapons and to determine the acceptable levels of troop concentration within an established constraint of acceptable damage from a single weapon attack. Specifically, this will be accomplished by determining the number of holding areas (1000 meters in radius) and the number of dispersal areas (100 meters and 500 meters in radius) required, within the division zone, to support the jth defile control policy when a target is attacked by a single weapon of the ith type. The levels of concentration in holding areas will be considered as targets 1000 meters in radius; whereas the levels of

*Mean Values

concentration during movement from deployed positions to holding areas and the levels of concentration within the defiles will be considered as targets 500 meters and 1000 meters in radius, respectively.

Figure 14 is the fractional damage nomograph extracted from FM 101-31-3 (12). The fractional damage is a function of the two ratios, CEP/R_T and R_D/R_T where,

	R_D	is the radius of damage from the ith type weapon
	R_T	is the radius of target
and	CEP	is the circular error probable of the delivery means.

This nomograph reflects a complicated functional relationship. However, two reasonable assumptions greatly simplify the relationships between R_D, R_T, CEP and the fractional damage. These assumptions are:

a. No fractional damage to a target greater than 0.8 will be acceptable.

b. Protection from attack is required from the most accurate delivery means; therefore, the circular error probable will be small compared to the target radius i.e.:

$$0 < \frac{CEP}{R_T} \leq 0.1.$$

On the basis of these two assumptions it is apparent that the fractional damage to a target is independent of the circular error probable of the delivery means, when R_T is taken at a constant value. From this point the functional relationship between R_D, R_T and the fractional damage can be easily determined by regression

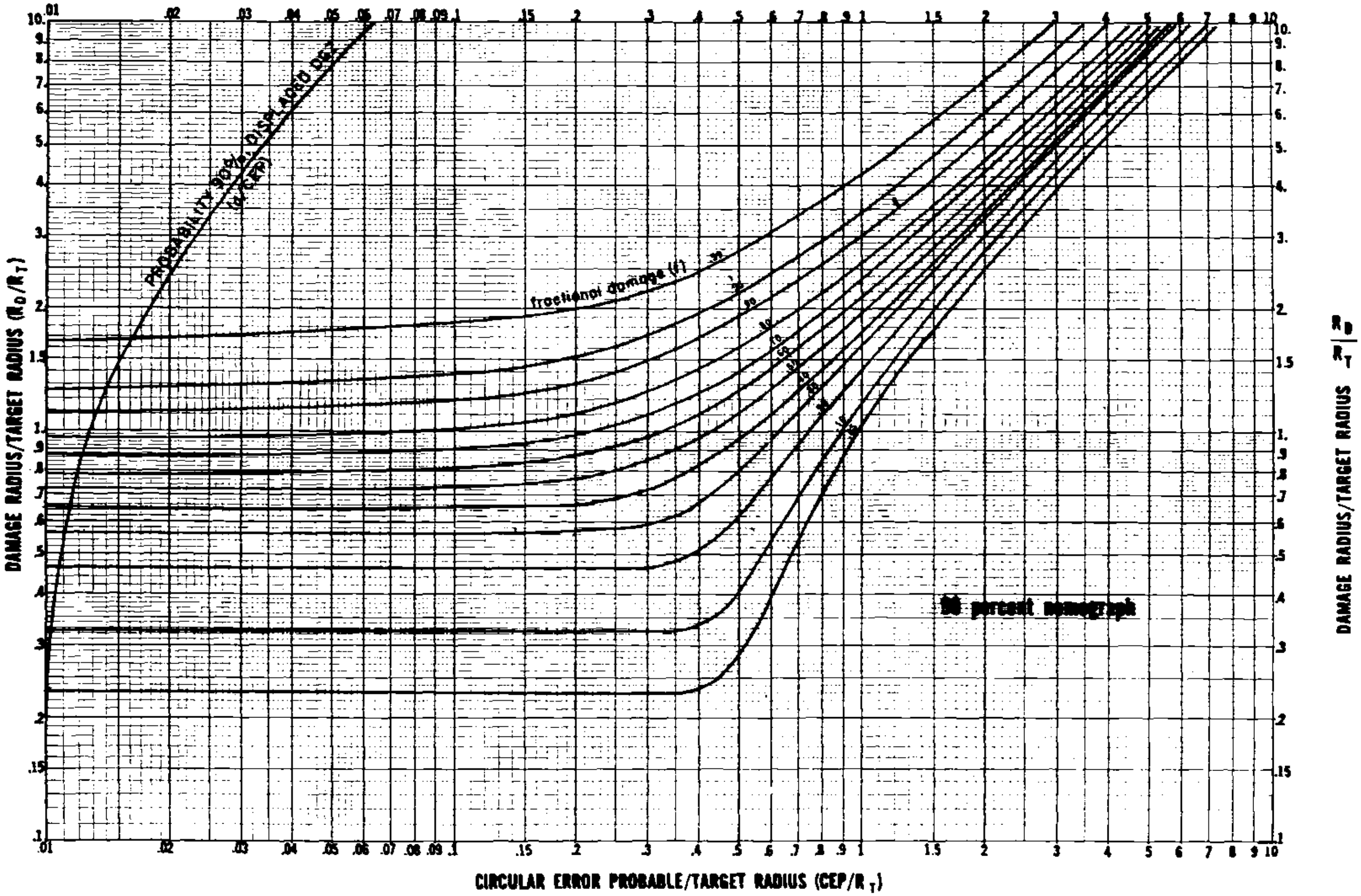

Figure 14. Fractional Damage Nomograph.

analysis.

Let x_i = Fractional Damage

and y_i = Ratio of R_D to R_T.

The corresponding values of x_i and y_i taken from Figure 14 are reflected in Table 9.

$$\frac{\sum_{i=1}^{9} x_i}{9} = 0.4056 \tag{1}$$

$$\frac{\sum_{i=1}^{9} y_i}{9} = 0.6172 \tag{2}$$

$$\sum_{i=1}^{9} (x_i - \bar{x})(y_i - \bar{y}) = 0.53452 \tag{3}$$

$$\sum_{i=1}^{9} (x_i - \bar{x})^2 = 0.56194 \tag{4}$$

Fitting the data to a straight line,

$$y = a + bx \tag{5}$$

Table 9. Fractional Damage versus the Ratio R_D/R_T

Fractional Damage x_i	Ratio R_D/R_T y_i
.05	.230
.10	.325
.20	.430
.30	.560
.40	.650
.50	.720
.60	.780
.70	.880
.80	.980

$$b = \frac{0.53452}{0.56194} = 0.95 \quad (6)$$

$$a = 0.6172 - 0.3852 = 0.232 \quad (7)$$

$$y = 0.232 + 0.95x \quad (8)$$

The resulting fit is reflected in Table 10 showing the y_i -observed and $\hat{y}_i$ -calculated values for the known values of x_i. From Table 10, the sum of the squares error is determined to be:

$$SSE = \frac{0.0039}{7} = 0.00056$$

Accepting the functional relationship from the linear regression;

Table 10. Observed versus Calculated Values of y_i

$\hat{y}_i$-Calculated	y_i-Observed	x_i
.237	.230	.05
.327	.325	.10
.424	.430	.20
.517	.560	.30
.612	.650	.40
.707	.720	.50
.799	.780	.60
.897	.880	.70
.992	.980	.80

Let x_i = Fractional Damage from ith Type Weapon

y_i = R_D/R_T from the ith Type Weapon

z_j = Level of Vehicle Concentration from the ith Defile Control Policy

n_{ij} = Number of Holding Areas (or Dispersal Areas) Required to Support the jth Policy when Attacked by the ith Type Weapon

k = Acceptable Vehicle Loss to a Single Weapon Attack

Recalling equation 8:

$$y_i = 0.95x_i + 0.232 \tag{9}$$

The fractional damage to a target will be;

$$x_i = \frac{kn_{ij}}{z_j} \tag{10}$$

By substituting equation 10 into equation 9 it is determined that:

$$y_i = \frac{0.95kn_{ij}}{z_j} + 0.232 \tag{11}$$

Solving equation 11 for n_{ij} gives:

$$n_{ij} = \frac{z_j(y_i - 0.232)}{0.95k} \tag{12}$$

From equation 12 the various defile control policies can now be examined in terms of the y_i values for various weapons and targets, the z_j values for various defile control policies and a particular value of k. The feasibility of any single policy can be judged from the values of n_{ij} for holding areas, movement dispersal areas, and defile dispersal areas. If n_{ij} is a greater quantity than what would reasonably be available, within a division gone, then the associated defile control policy is unacceptable under the condition of attack by the ith sized weapon.

Crossing Means Prediction and Defile Control

Recall that nine defile control policies were considered in the simulations of plans B and E. From the results of Model V we are interested in the levels of concentration in the defiles, holding ares and in moving from deployed positions to the holding areas. Additionally, we are concerned with the non-utilization of crossing means during the conduct of the entire crossing. The simulation results in regard to these factors are extracted and shown in Table 11.

As examples of the data output capabilities of Dynamo, plots of the variables of interest are shown in Figures 15 and 16. Figure 15 relates to plan B and reflects the time varying behavior of the variables CSSC (class 60 vehicles successfully crossed), CTSC (class 12 vehicles successfully crossed), ASCR (actual class 60 crossing rate), ATCR (actual class 12 crossing rate) and TVID (total vehicles in the defiles). Figure 16 relates to plan E and reflects the time-varying behavior of the variables SMPT (class 60 means predicted time), SDT (class 60 downtime), TDT (class 12 downtime), SDEL (class 60 holding area delay), TVHA (total vehicles in holding areas), CSID (class 60 vehicles in defiles) and CTID (class 12 vehicles in defiles). Additional plots shown in the Appendix to this study reflect the time varying behavior of the following variables:

BRIO	Bridges in Operation
MARO	Mobile Assault Rafts in Operation
RFTO	M4T6 Rafts in Operation
LTRO	Light Tactical Rafts in Operation
MSCR	Maximum Class 60 Crossing Rate
MTCR	Minimum Class 12 Crossing Rate
TCOS	Class 12 Vehicles Crossing on Class 60 Means

The printed output is comprehensive of the crossing and provides values of forty variables of interest over the time span of the crossing. An example of this data output is shown in Figure 17.

From the data output reflected in Table 11 an analysis of defile control policies can be made by the use of equation 12 from the previous section.

Table 11. Levels of Vehicle Concentration and Crossing Means Down Time

Plan	Defile Level	Predictive Capability	TVID Max Mean	TVHA Max Mean	SDT Max Mean	TDT Max Mean	CSMV Max	CTMV Max
B	7.5	60	125	1844	0	0	248	612
			90	954	0	0		
	11.25	60	176	1816	0	0	248	612
			119	924	0	0		
	15	60	270	1765	0	0	248	612
			172	872	0	0		
	7.5	45	119	1677	.09	0	237	637
			79	817	.0004	0		
	11.25	45	175	1651	0	0	237	637
			110	785	0	0		
	15	45	273	1610	0	0	237	637
			160	735	0	0		
	7.5	30	81	1546	.35	.25	224	631
			50	736	.009	.0035		
	11.25	30	85	1531	.26	.16	223	630
			63	701	.006	.0009		
	15	30	170	1463	.21	0	222	630
			112	631	.004	0		
E	7.5	60	171	2421	0	0	213	962
			111	1063	0	0		
	11.25	60	219	2377	0	0	213	962
			143	1031	0	0		
	15	60	318	2289	0	0	213	962
			214	960	0	0		
	7.5	45	168	2224	.077	0	234	1019
			104	896	.0004	0		
	11.25	45	212	2192	0	0	234	1019
			135	864	0	0		
	15	45	299	2122	0	0	234	1019
			201	798	0	0		
	7.5	30	142	1713	.388	0	210	909
			73	634	.0068	0		
	11.25	30	204	1664	.226	0	210	909
			110	600	.0015	0		
	15	30	315	1609	0	0	210	909
			158	549	0	0		

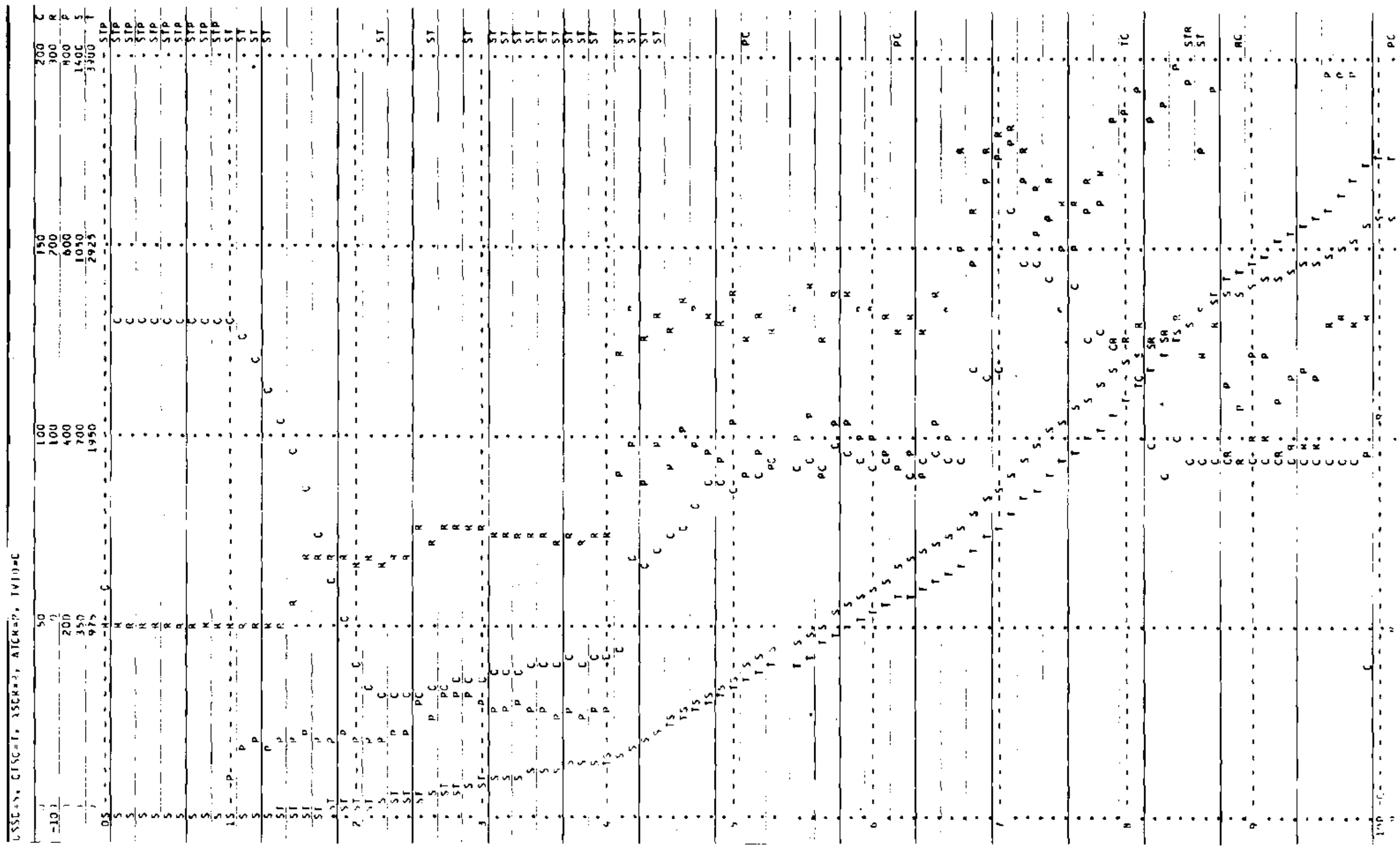

Figure 15. Example Plot 1, Variables of Interest.

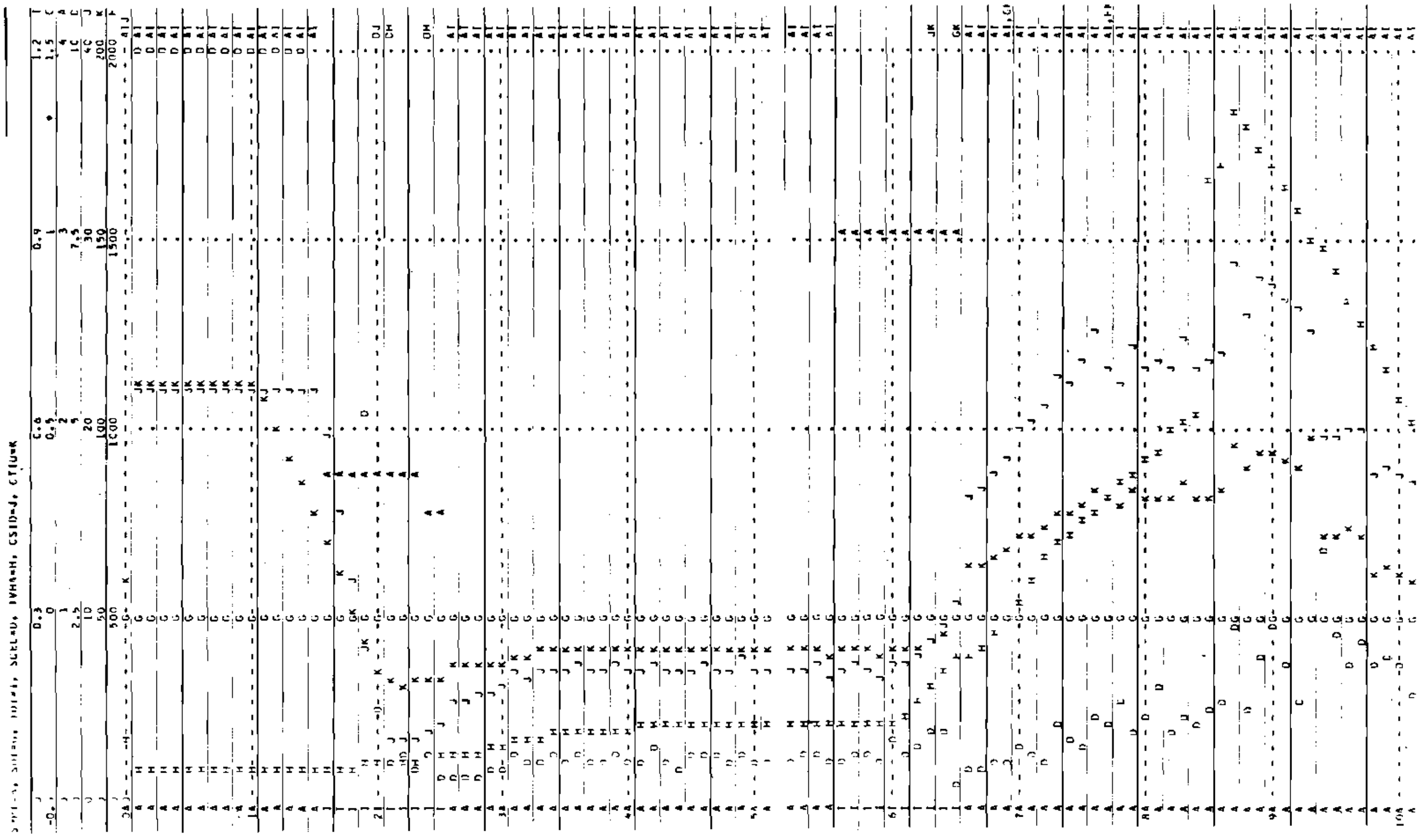

Figure 16. Example Plot 2, Variables of Interest.

TIME	SDT RSHC RHC ATVID BRID	TDT RTHC RDC ATVHA HARD	TVID RSDC CSHA ASDT RFTO	TVHA RTDC CTHA ATDT LTRU	SHDR CSSC ASCR CSMR MSCR	THDR CTSC ATCR CTMR MTCR	SDHR CSC TCOS SDEL	TDHR CTD CTMV	SHAR CSMV THAR
5.500	.00000	.00000	47.65	217.6	69.01	162.2	68.09	160.0	91.8
	.645	1.07	.101	.25	251.5	626.7	747.5	2438.1	58.47
	1.46	.32	44.59	173.0	68.08	159.58	88.43	110.44	.206
	.00	.0	.00000	.00000	71.77	168.65	.0		
	.0000	4.0000	14.000	14.000	112.29	71.553			
5.600	.00000	.00000	48.74	220.3	79.95	187.9	317.07	745.1	78.2
	.563	.94	.091	.22	258.5	643.1	740.5	2421.7	57.86
	1.28	.28	44.87	175.5	78.67	184.88	103.60	107.23	.139
	.00	.0	.00000	.00000	71.80	168.72	.0		
	.0000	4.0000	14.000	14.000	130.47	81.276			
5.700	.00000	.00000	49.19	215.0	61.87	145.4	266.42	626.1	76.3
	.660	1.09	.111	.27	266.2	661.2	709.6	2349.0	81.61
	1.49	.34	44.26	170.7	66.10	155.34	89.43	166.32	.135
	.00	.0	.00000	.00000	71.84	168.82	.0		
	.0000	4.0000	14.000	14.000	110.82	65.918			
5.800	.00000	.00000	49.04	210.8	59.59	140.0	275.14	646.6	62.4
	.633	1.03	.106	.26	273.2	677.6	681.3	2282.7	102.82
	1.42	.33	44.30	166.5	69.27	160.43	86.54	220.50	.159
	.00	.0	.00000	.00000	75.49	177.41	.0		
	.0000	4.0000	14.000	14.000	111.54	73.892			
5.900	.00000	.00000	47.51	215.0	81.79	192.2	303.97	714.3	94.2
	.590	.95	.091	.23	280.0	693.6	653.8	2218.0	123.20
	1.31	.29	45.07	169.9	75.42	177.24	95.62	266.81	.227
	.00	.0	.00000	.00000	93.73	220.27	.0		
	.0000	4.0000	14.000	14.000	123.23	81.617			
6.000	.00000	.00000	49.81	225.8	54.89	129.0	259.49	609.8	125.0
	.723	1.17	.116	.28	287.5	711.3	623.5	2146.7	143.13
	1.61	.35	47.26	179.5	64.39	151.31	78.40	310.23	.226
	.00	.0	.00000	.00000	119.93	281.83	.0		
	.0000	4.0000	14.000	14.000	103.58	72.911			
6.100	.00000	.00000	49.27	245.2	71.57	168.2	279.37	656.5	162.5
	.752	1.17	.106	.26	294.1	726.9	596.8	2084.1	157.73
	1.62	.33	52.87	192.4	69.32	162.90	83.42	343.84	.348
	.00	.0	.00000	.00000	147.58	346.82	.0		
	.0000	4.0000	14.000	14.000	111.03	79.474			
6.200	.00000	.00000	50.62	272.0	74.71	175.6	267.38	716.6	162.0
	.942	1.33	.116	.27	301.0	742.9	569.3	2014.9	167.47
	1.88	.35	63.43	203.6	66.34	155.91	77.36	379.83	.406
	.00	.0	.00000	.00000	173.97	408.82	.0		
	.0000	4.0000	14.000	14.000	105.02	78.549			
6.300	.00000	.00000	53.63	312.2	75.29	176.9	277.88	744.7	196.4
	1.071	1.46	.125	.28	307.8	759.0	541.8	1941.1	175.82
	2.07	.36	74.88	237.3	68.95	162.03	88.04	406.75	.458
	.00	.0	.00000	.00000	195.85	460.25	.0		
	.0000	4.0000	14.000	14.000	112.97	73.984			
6.400	.00000	.00000	56.43	356.8	83.73	196.8	292.26	783.2	239.8
	1.184	1.57	.130	.27	314.9	775.7	513.1	1864.3	184.34
	2.26	.36	87.07	263.8	72.51	170.41	93.40	432.36	.485
	.00	.0	.00000	.00000	213.30	505.51	.0		
	.0000	4.0000	14.000	14.000	119.21	77.012			
6.500	.00000	.00000	60.77	402.0	344.99	810.7	757.85	2031.1	179.0
	.528	.63	.058	.11	322.4	793.4	482.8	1783.0	193.09
	.78	.12	99.84	302.1	188.04	441.89	362.19	460.59	.559
	.00	.0	.00000	.00000	227.27	547.81	.0		
	1.0000	4.0000	14.000	14.000	478.23	79.702			
6.600	.00000	.00000	79.78	399.6	175.71	412.9	176.01	471.7	255.0
	.543	.73	.094	.15	341.3	837.7	406.7	1579.1	248.25
	.82	.16	96.20	303.4	176.01	413.61	338.96	605.51	.730
	83.34	390.0	.00000	.00000	239.30	588.05	.0		
	1.0000	4.0000	14.000	14.000	447.58	74.651			
6.700	.00000	.00000	80.01	425.9	221.32	520.1	196.51	526.6	241.1
	.520	.70	.084	.14	359.7	881.0	388.3	1529.8	241.77
	.78	.15	102.62	323.3	196.51	461.79	386.07	591.48	.771
	81.61	406.3	.00000	.00000	257.60	645.90	.0		
	1.0000	4.0000	14.000	14.000	505.83	75.716			

Figure 17. Example Printed Output, Variables of Interest.

Recalling that:

$$n_{ij} = \frac{z_j(y_i - 0.232)}{0.95k}$$

and establishing a value for k of 20, each policy will be examined in terms of various sized weapons to determine the number of holding areas, movement dispersal areas and defile dispersal areas required to support that policy for each weapon being considered. For example, consider plan B where an 11.25 minute level is established for defile concentration and the predictive capability is 30 minutes. The appropriate z_j values are reflected in Table 12. The appropriate y_i values for holding areas, movement dispersal areas and defile dispersal areas are shown in Table 13 for both tanks and wheeled vehicles when attacked by a 2 kiloton (KT) weapon. It should be remembered that y_i is the ratio of R_D to R_T. The number of holding areas required using a z_j maximum of 1531 vehicles for a homogeneous target of wheeled vehicles is determined as follows:

$$n_{ij} = \frac{z_j(y_i - 0.232)}{0.95k} = \frac{(1532)(0.118)}{(0.95)(20)} = 9.5$$

$$n_{ij} \approx 10$$

This result indicates that 10 holding areas within the division zone are necessary to be within the acceptable damage level, against a 2KT single weapon attack, at the time of maximum vulnerability. Similarly, the number of movement dispersal areas and defile dispersal areas required at the time of maximum vulnerability are determined as follows:

Table 12. Vehicle Concentration Values for Plan B, 11.25 Minute Defile Level and 30 Minute Prediction

Level	z_j(max)	$\bar{z}_j$
TVID	85	63
TVHA	1531	701
CSMV	223	...
CTMV	630	...

Table 13. R_D to R_T Values for a 2KT Weapon

Vehicle Class	Holding Areas	Movement Dispersal Areas	Defile Dispersal Areas
Tanks	0.26	0.52	2.6
Wheeled	0.35	0.70	3.6

$$n_{ij} = \frac{(630)(0.468)}{(0.95)(20)} = 15.5$$

$n_{ij} \approx$ 16 movement dispersal areas for wheeled columns

$$n_{ij} = \frac{(223)(0.288)}{(0.95)(20)} = 3.4$$

$n_{ij} \approx$ 4 movement dispersal areas for tank columns

$$n_{ij} = \frac{(85)(3.268)}{(0.95)(20)} = 14.6$$

$n_{ij} \approx$ 15 defile dispersal areas.

It must be remembered that this analysis is making use of a hypothetical family of weapons. The results for this example are interpreted accordingly. The division zone of attack is 36 kilometers wide and 30 kilometers deep. Five kilometers of the depth constitute the crossing area on the near (friendly) side of the river (4). In a zone of this size it can reasonably be expected that 8 to 12 holding areas, 20 to 24 movement dispersal areas and 16 to 20 defile dispersal areas, of the sizes previously specified, would be available from a terrain view (4, 10). Quantities in excess of these values could be expected only in the unusual circumstances of a particularly wide division zone or in a terrain area that provided extraordinary trafficability and routes of communication. So in this example the defile control policy is acceptable in terms of vulnerability to a 2KT single weapon attack. Applying this analysis technique to all the considered defile control policies, in terms of various weapons, provides the results which are presented in Tables 15 and 16 for crossing plans B and E, respectively. The y_i values used in determining these n_{ij} figures are reflected in Table 14.

Table 14. R_D to R_T Values for Various Weapons

Weapon Size	Vehicle Class	Holding Areas	Movement Dispersal Areas	Defile Dispersal Areas
1KT	Tanks	.250	.50	2.50
	Wheeled	.300	.60	3.00
2KT	Tanks	.260	.52	2.60
	Wheeled	.350	.70	3.50
5KT	Tanks	.300	.60	3.00
	Wheeled	.500	1.00	5.00
10KT	Tanks	.375	.75	3.75
	Wheeled	.650	1.30	6.50

Several implications are apparent from the data contained in Tables 11, 15 and 16. They are the following:

a. In a non-nuclear environment the existing defile control doctrine is adequate for the conduct of assault river crossings.

b. Prediction of increased crossing means at a time equal to the longest average movement time results in full utilization of crossing capability; prediction

Table 15. Holding and Dispersal Area Requirements, Plan B

Weapon Size	Defile Control Policy	Holding Areas Max/Mean	Movement Dispersal Areas Tank/Wheel	Defile Dispersal Areas Max/Mean
1KT	7.5/60	7/4	4/12	19/14
	11.25/60	7/4	4/12	26/18
	15/60	7/4	4/12	40/25
	7.5/45	6/3	4/13	18/12
	11.25/45	6/3	4/13	26/17
	15/45	6/3	4/13	40/24
	7.5/30	6/3	4/13	12/8
	11.25/30	6/3	4/13	13/10
	15/30	6/3	4/13	25/17
2KT	7.5/60	12/6	4/16	22/16
	11.25/60	12/6	4/16	31/21
	15/60	11/6	4/16	47/30
	7.5/45	11/6	4/16	21/14
	11.25/45	11/5	4/16	31/19
	15/45	11/5	4/16	47/28
	7.5/30	10/5	4/16	14/9
	11.25/30	10/5	4/16	15/11
	15/30	10/4	4/16	30/20
5KT	7.5/60	26/14	5/25	32/23
	11.25/60	26/14	5/25	45/30
	15/60	unacceptable at 2 KT		
	7.5/45	24/12	5/26	30/20
	11.25/45	24/12	5/26	45/28
	15/45	unacceptable at 2KT		
	7.5/30	22/11	5/26	21/13
	11.25/30	22/10	5/26	22/16
	15/30	21/9	5/26	43/29
10KT	7.5/60	unacceptable at 5KT		
	11.25/60	unacceptable at 5KT		
	15/60	unacceptable at 2KT		
	7.5/45	37/18	7/36	40/27
	11.25/45	unacceptable at 5KT		
	15/45	unacceptable at 2KT		
	7.5/30	34/17	7/36	27/17
	11.25/30	34/16	7/36	28/21
	15/30	unacceptable at 5KT		

Table 16. Holding and Dispersal Area Requirements, Plan E

Weapon Size	Defile Control Policy	Holding Areas Max/Mean	Movement Dispersal Areas Tanks/Wheel	Defile Dispersal Areas Max/Mean
1KT	7.5/60	9/4	4/19	25/17
	11.25/60	9/4	4/19	32/21
	15/60	9/4	4/19	47/32
	7.5/45	8/4	4/20	25/16
	11.25/45	8/4	4/20	31/20
	15/45	8/3	4/20	44/30
	7.5/30	7/3	3/18	21/11
	11.25/30	6/3	3/18	30/17
	15/30	6/2	3/18	46/24
2KT	7.5/60	15/7	4/24	30/20
	11.25/60	unacceptable at 1KT		
	15/60	unacceptable at 1KT		
	7.5/45	14/6	4/27	29/18
	11.25/45	14/6	4/27	37/24
	15/45	unacceptable at 1KT		
	7.5/30	11/4	4/23	25/13
	11.25/30	10/4	4/23	36/19
	15/30	unacceptable at 1KT		
5KT	7.5/60	35/16	5/39	43/28
	11.25/60	unacceptable at 1KT		
	15/60	unacceptable at 1KT		
	7.5/45	unacceptable at 2KT		
	11.25/45	unacceptable at 2KT		
	15/45	unacceptable at 1KT		
	7.5/30	25/9	5/37	36/19
	11.25/30	24/8	5/37	52/28
	15/30	unacceptable at 1KT		

at a time equal to the shortest average movement time does result in non-utilization of crossing means, but it is short-lived and over the crossing's span does not exceed a mean value of one per cent.

c. An allowed defile concentration level of 15 minutes is unnecessary to effective crossing means utilization, and therefore results in defile congestion which is unnecessary.

d. In a tactical nuclear environment*, of even a limited nature, the existing defile control doctrine is marginal at best. Under existing doctrine, forward movement of units should commence at the latest feasible time, and defile levels must be severely reduced. The necessary reduction of vulnerability will result in some non-utilization of crossing means.

e. Concentration levels must necessarily increase with the number of bridges which the crossing plan provides. In a tactical nuclear environment the resulting concentration levels should be one of the criteria for the comparison of crossing plans.

A number of specific conclusions and recommendations ensue from the foregoing implications. Discussion of these will be reserved for the concluding chapter.

The Effect of Random Outages on Defile Control

The random outage portion of Model VI performed its simulation as expected. The actual versus theoretical average number of rafts and bridges in operation during the simulation runs for plan B are reflected in Table 17.

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*Analysis based on hypothetical weapons.

Table 17. Actual Versus Theoretical Average Number of Bridges and Rafts in Operation, Plan B

Crossing Means	Actual Number in Operation	Theoretical Number in Operation
Bridges	1.76	1.80
Mobile Assault Rafts	3.85	3.84
M4T6 Rafts	12.24	12.60
Light Tactical Rafts	12.97	13.30

The unexpected outages of crossing means did have some effect upon the levels of troop concentration and the downtime of available crossing means. Though only a limited number of runs were made with Model VI and the random number seed was changed only one time, the effect of unexpected outages on defile control measures was not observed to be adverse. However, it must be recognized that no firm conclusions should be drawn from the data output without the benefit of more replications, which the variability, observed in the two runs made, seems to demand. The pertinent data outputs from the two runs made with plan E* are compared to the results obtained from Model V in Table 18.

One additional factor should not be overlooked. When a significant unexpected loss of crossing means occurs the ratios of troop concentration to crossing capability will also change significantly. The division should be able to respond to this situation fairly rapidly in the defiles, but there is little that can be done

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*7.5 minute defile level and 30 minute prediction.

Table 18. Defile Control Variables of Plan E, Model V Versus Model VI

Model and Run	TVID Max/Mean	TVHA Max/Mean	SDT Max/Mean	TDT Max/Mean	CSMV Max	CTMV Max
V*	168/104	2224/896	.077/.0004	0/0	234	1019
VI-1	137/104	2178/914	.055/.0003	0/0	203	917
VI-2	159/97	2174/849	.059/.0003	0/0	220	989

within the holding areas. The periods of vulnerability will simply be extended in time. In one of the runs in Model VI-E a bridge loss occurred at 7.8 hours. A comparison of the RDC (defile level to crossing capability) and RHC (holding area level to crossing capability) ratios of plans V and VI over this period is shown in Figures 18 and 19.

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*Run number is not applicable to Model V.

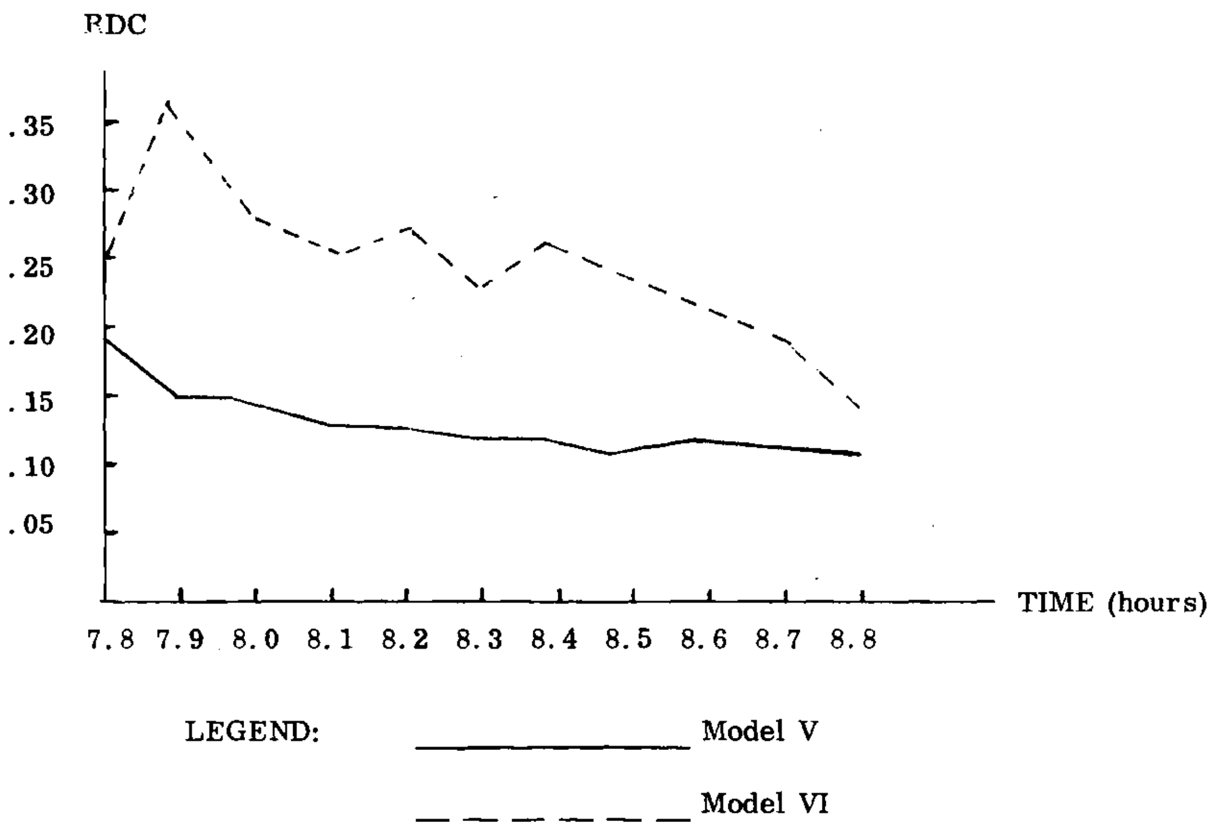


Figure 18. RDC Values, Model V Versus Model VI

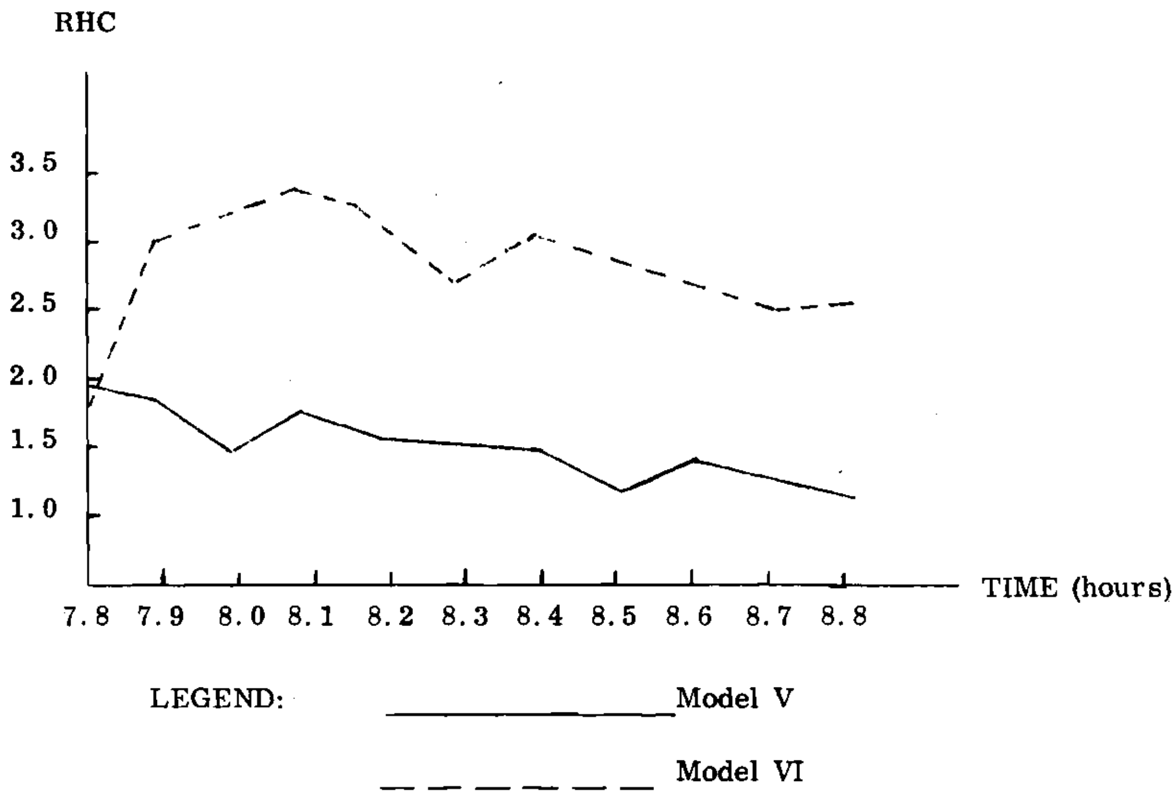


Figure 19. RHC Values, Model V Versus Model VI

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Defile Control Doctrine

The U. S. Army's existing doctrine for controlling the movement of units during the negotiation of defiles is sound in concept, when taken within the confines of a non-nuclear environment. Levels of unit concentration can be kept within the necessary constraints without resulting in a significant non-utilization of crossing capability. There are several essentials to the adequacy of this doctrine in execution. Communications within the division must be unfailing to provide for transmission of the steady stream of orders needed to implement the continuously changing rates of movement. Accurate prediction of increased crossing capability by the division is equally essential. Without such prediction, the only possible way to avoid crossing means downtime would be to greatly extend the time-periods of maximum concentration within the holding areas. Lastly, the reaction of units to orders must be accomplished with alacrity to minimize the time lag between desired conditions and actuality.

In tactical nuclear environment present defile control doctrine appears questionable, in terms of the hypothetical family of nuclear weapons. Levels of troop concentration simply cannot be reduced to the acceptable level established by the results of the research. What seems to be demanded is an assault river crossing doctrine that avoids defile negotiation, thereby eliminating the unacceptable concentration of forces. The crux of the problem is with the division's equipment. A marked increase in amphibious and heliborne capabilities for combat, logistical and administrative elements of the division should provide the impetus for revised doctrine. Additional areas of vital interest should include investigating the possible means to increase our suppressive fire and self-protective capabilities on the nuclear battlefield.

Crossing Plans and Unit Integrity

Higher levels of troop concentration must necessarily occur in plan E as opposed to plan B. Although this increase amounts to approximately 60 per cent, on the average, the increased levels are tolerable in a non-nuclear environment. When this increased concentration is compared to the 60 per cent gain in the number of class 60 vehicles crossed at K+6 hours and the 25 per cent savings in time for crossing the entire division, plan E becomes the desired alternative. The potential gain in maintaining the momentum of the attack is clearly worth the increased risk.

The importance of maintaining unit integrity was discussed in the chapter on the Dynamo Models. A part of the computer routine made use of a simple mathematical model in determining the number of class 12 vehicles crossing on class 60 means at any time. It will be recalled that the crossing capabilities were the independent variables and that they were tied together by two parameters, α and β, which described the crossing plan and the tactical plan.

In maintaining unit integrity without causing a non-utilization of crossing means, the crossing plan must be a servant of the tactical plan. Though one can hardly imagine the division engineer and other staff officers continuously applying some mathematical formula during conduct of the crossing, such analysis can profitably be done beforehand. In fact, the computations can be accomplished long before the execution of an assault river crossing. Though there are many conceivable tactical and crossing plans, the values of the parameters α and β must each lie within the bounds of a describable range. These ranges can be subdivided into a number of intervals and then a finite number of combinations can be determined. The standard type raft load listings, which should be a part of every unit's standard operating procedure (4, 10, 11), can be catalogued according to these various combinations of α and β. With unit standard operating procedures so organized, the crossing plan for a particular situation can be rapidly put together in a manner that does support the tactical plan.

Extensions of the River Crossing Model

A vital aspect of any tactical situation is the terrain. Without consideration being given to the factors of trafficability and obstacles to movement, fields of fire, cover and concealment, routes of communication, and terrain objectives, the interaction of opposing forces cannot be realistically represented in building computer simulations of tactical operations. The computer modeling of terrain has proven to be one of the most difficult and complex aspects of military digital simulation (3, 13, 36, 39).

This research investigated crossing plans and defile control policies with the assumption that the effects of any enemy action would be uniform to competitive alternatives. This is admittedly a broad assumption. Model VI includes about 300 variables, and therefore uses approximately one-fifth of Dynamo's present capability. An investigative research into the modeling of terrain in Dynamo is recommended. A successful realization of such research would add greatly to the usefulness of Dynamo in the simulation of tactical operations.

The addition of a realistic terrain portion to the river crossing model would allow the effects of enemy action to be considered in a stochastic way. With such a capability, crossing plans and defile control doctrines can be studied in a Monte Carlo sense, giving the enemy his deserved due as a capable and uncooperative adversary.

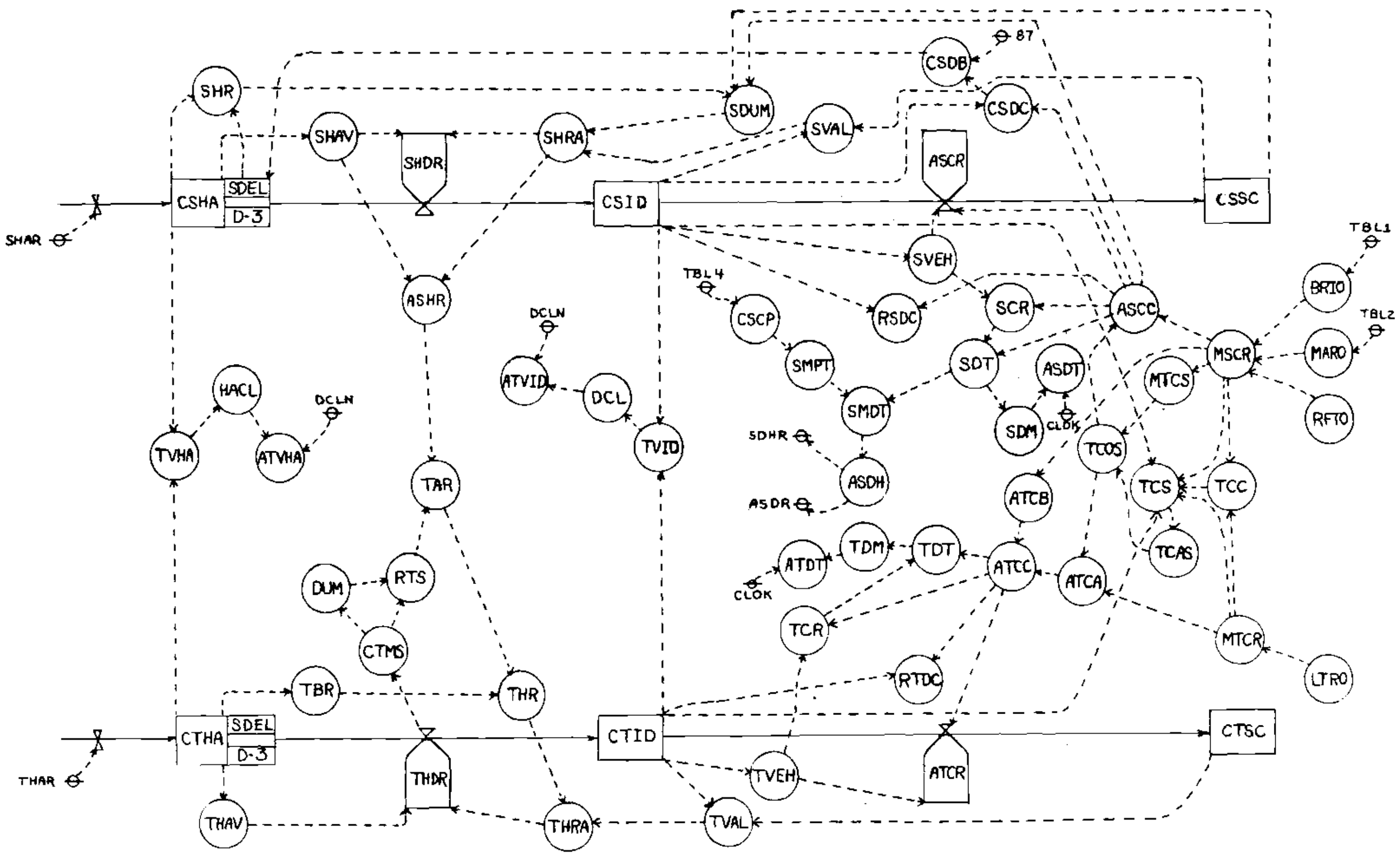
A Special Purpose Tactical Simulator

The literature survey portion of this research has indicated that the development of military simulations in the general-purpose languages has been extensive. It has further indicated that a variety of complex logistical operations can be realistically and easily simulated with either GPSS III or Simscript. The first attempt at a special-purpose language for the simulation of tactical operations is evidently Militran.

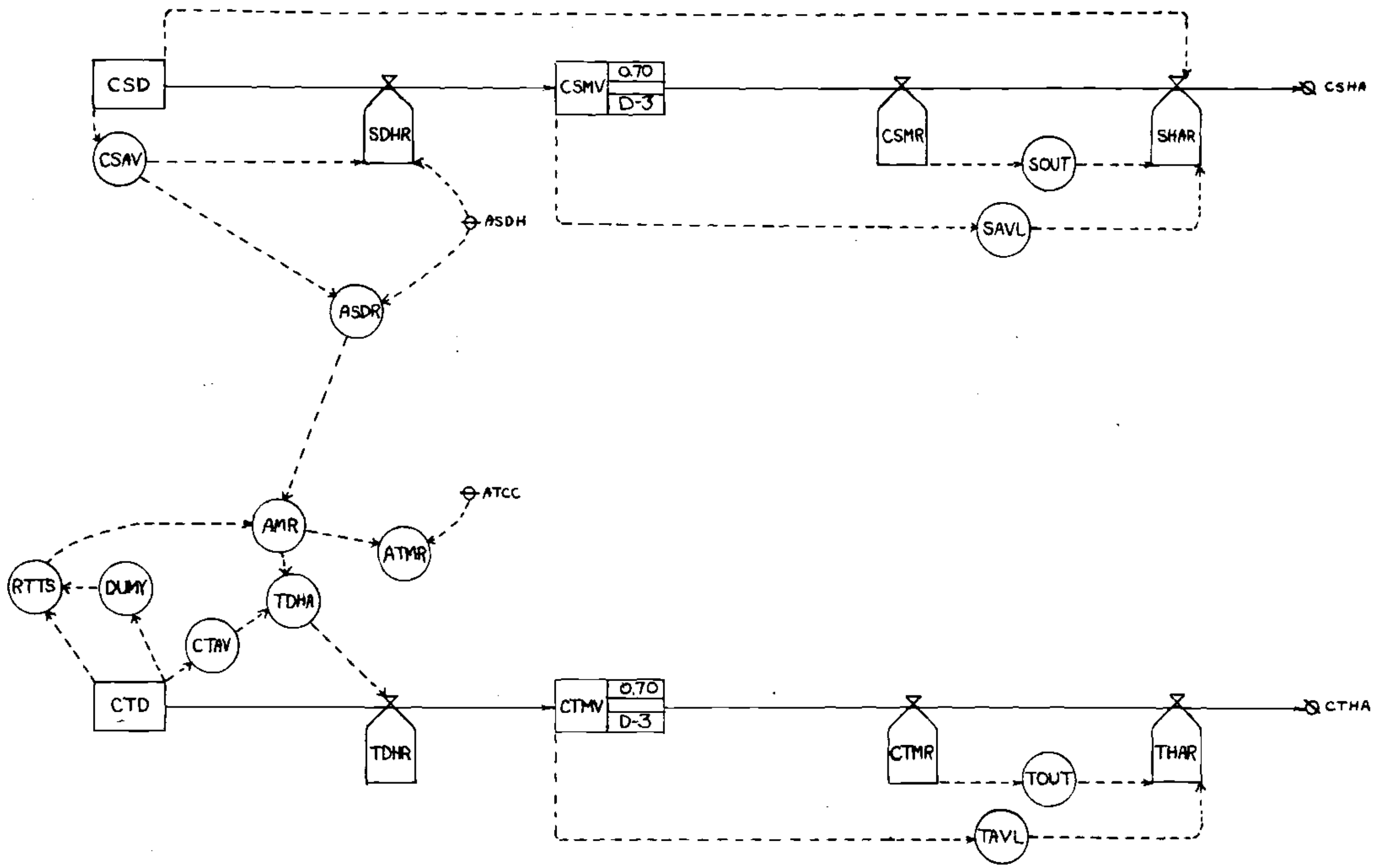
The results of this research, when coupled with extensions that appear logical and possible, indicate that Dynamo could conceivably be developed into a special purpose simulator for tactical operations. The greatest need is for flexible sub-routines that facilitate the realistic modeling of terrain, with a degree of programming effort that is not prohibitive. With this single added capability, the modeling of effectiveness ratios for opposing forces and the resulting tactical behavior is a relatively easy task in Dynamo (1, 8, 14, 25).

For the military operations analyst, a special purpose tactical simulator would be a welcome and powerful tool in the study of weapons systems, unit organizations, tactical doctrine and operational plans.

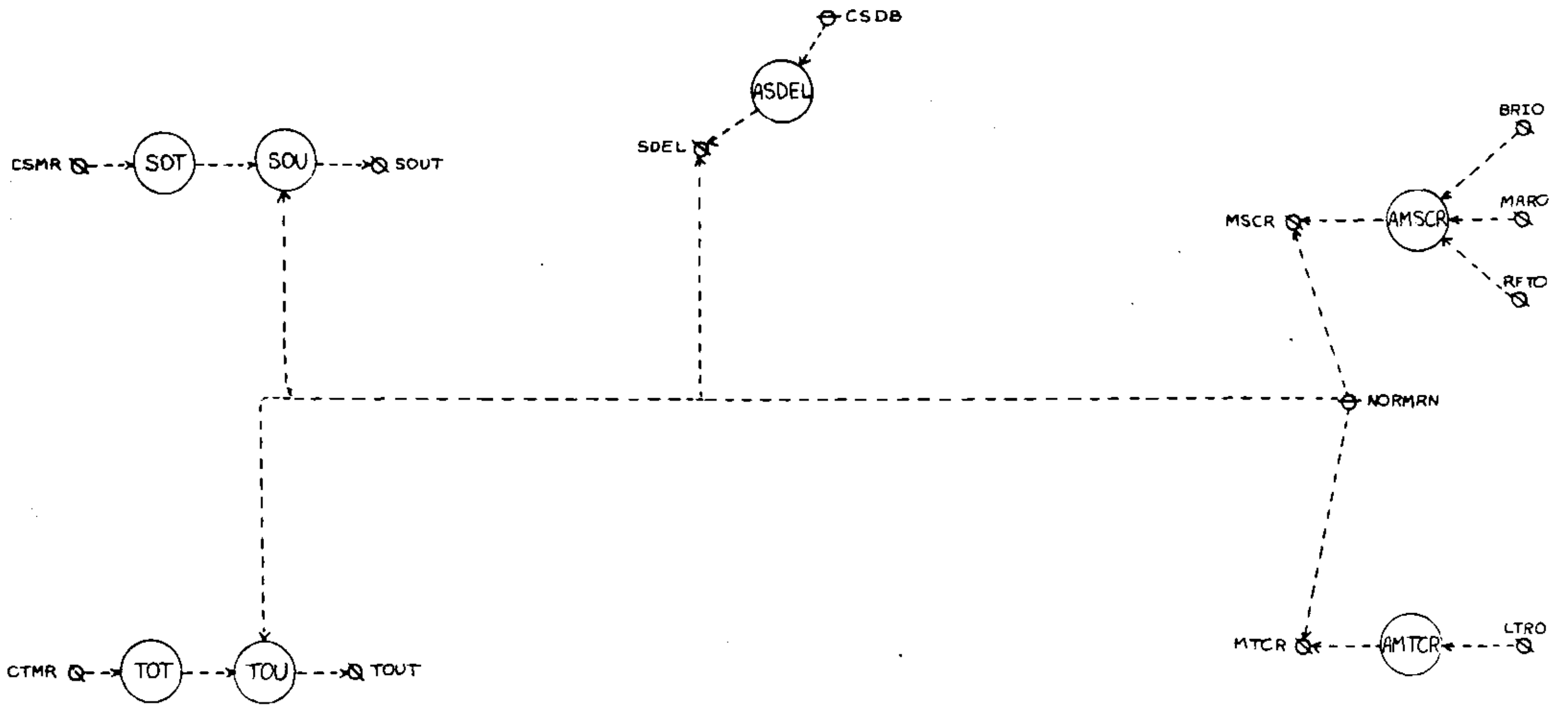
APPENDIX



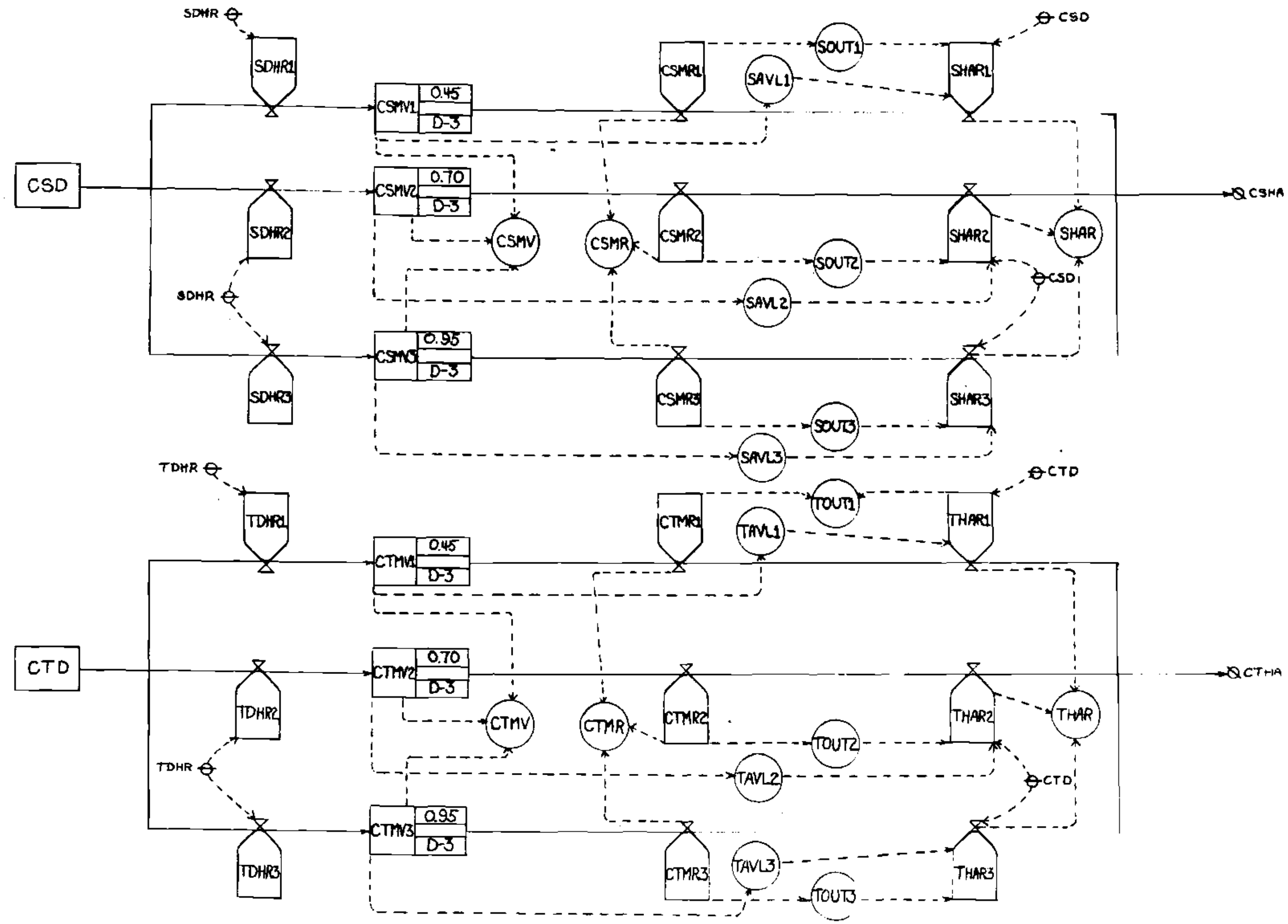
Holding and Crossing Area Portion, Model I



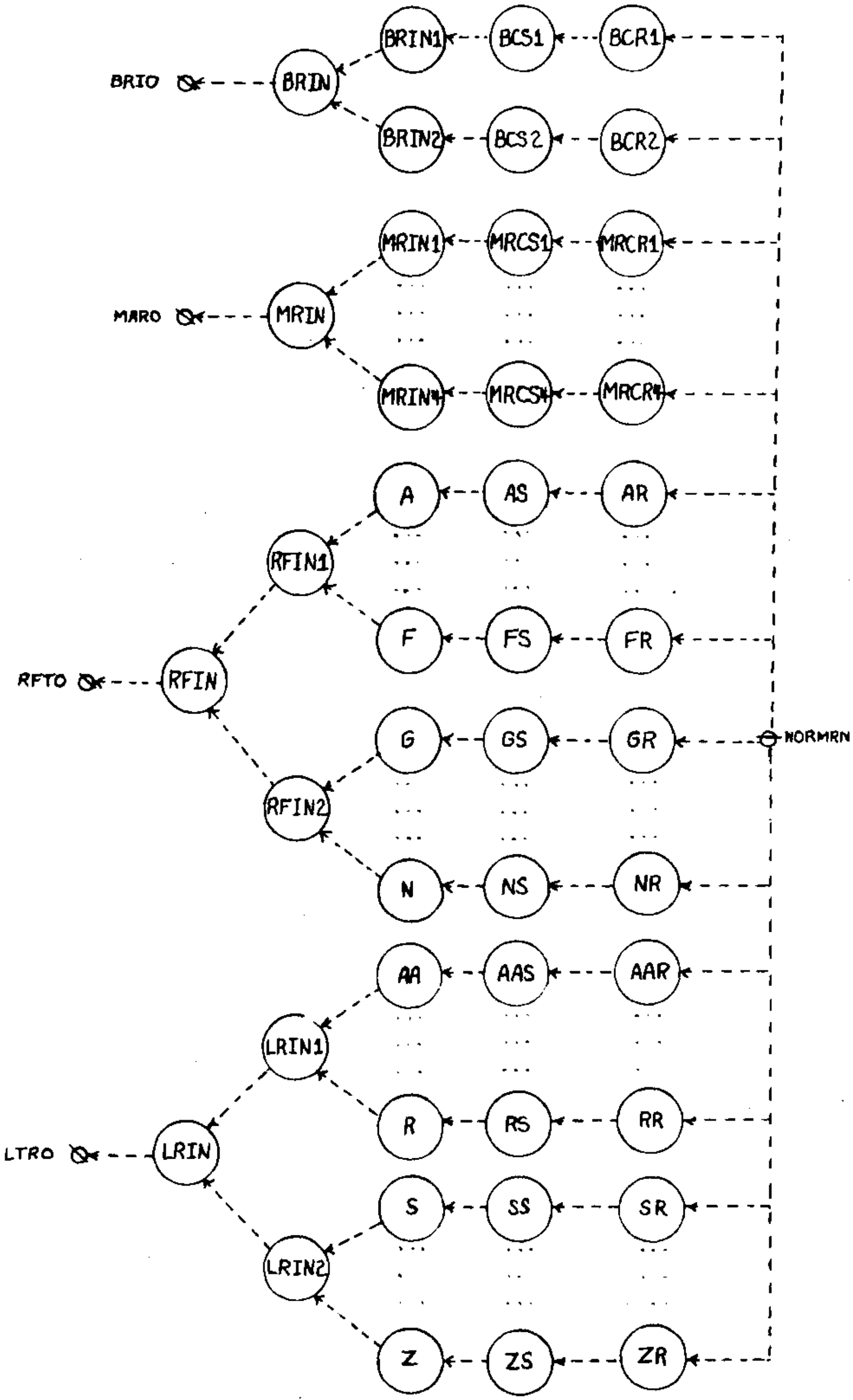
Deployed and Movement Portion, Model I



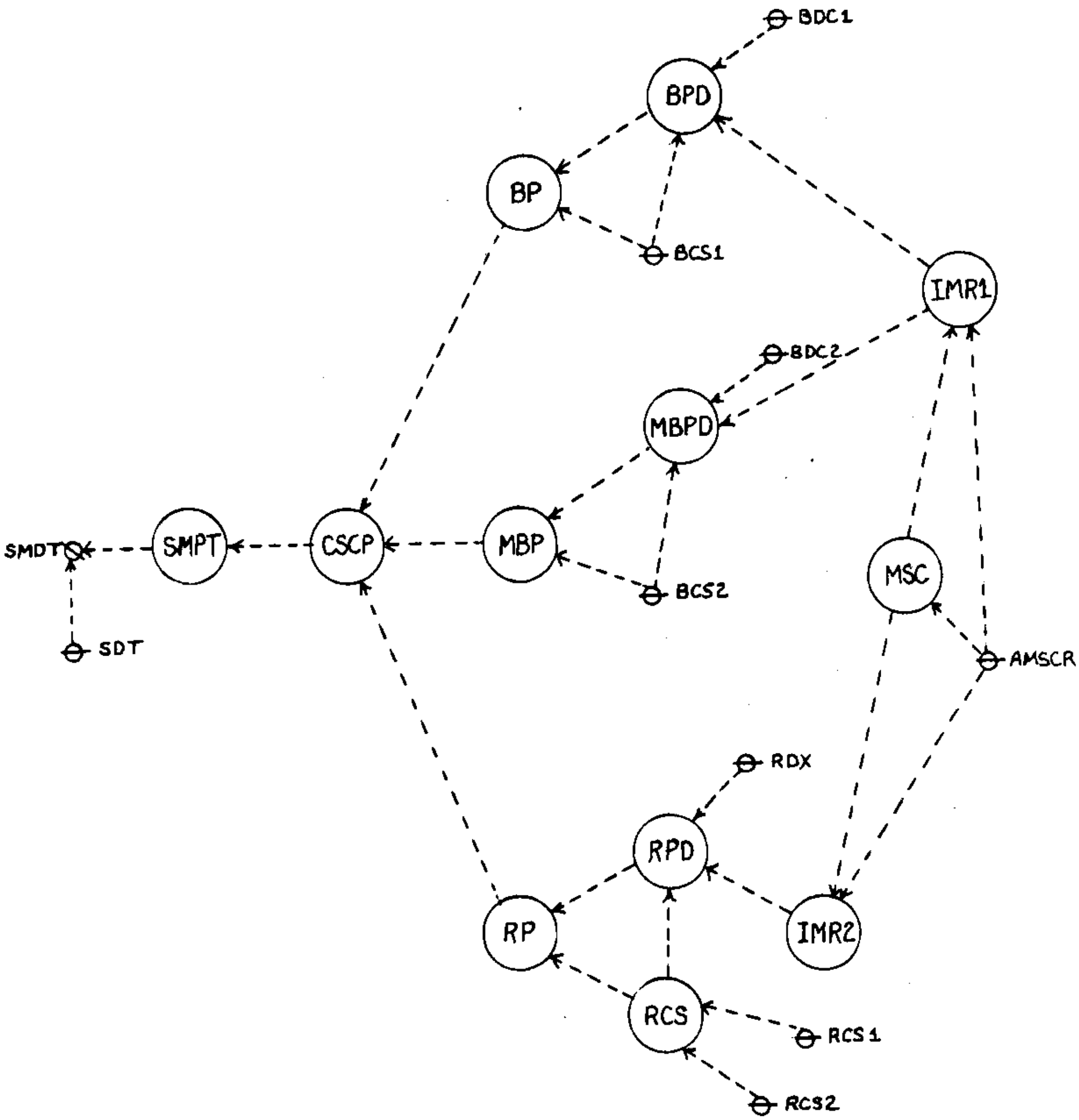
Flow Diagram Changes, Model II



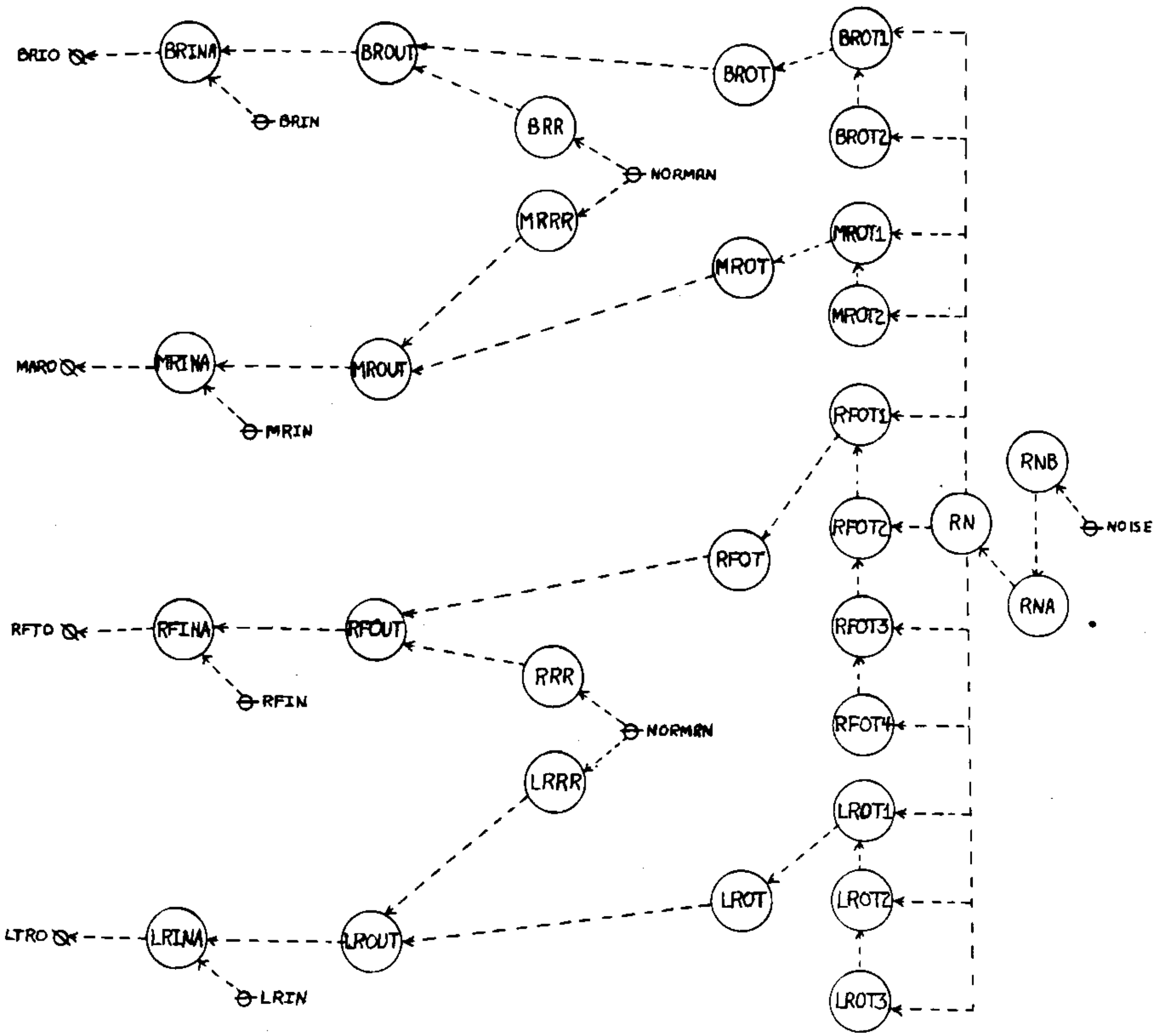
Flow Diagram Changes, Model III



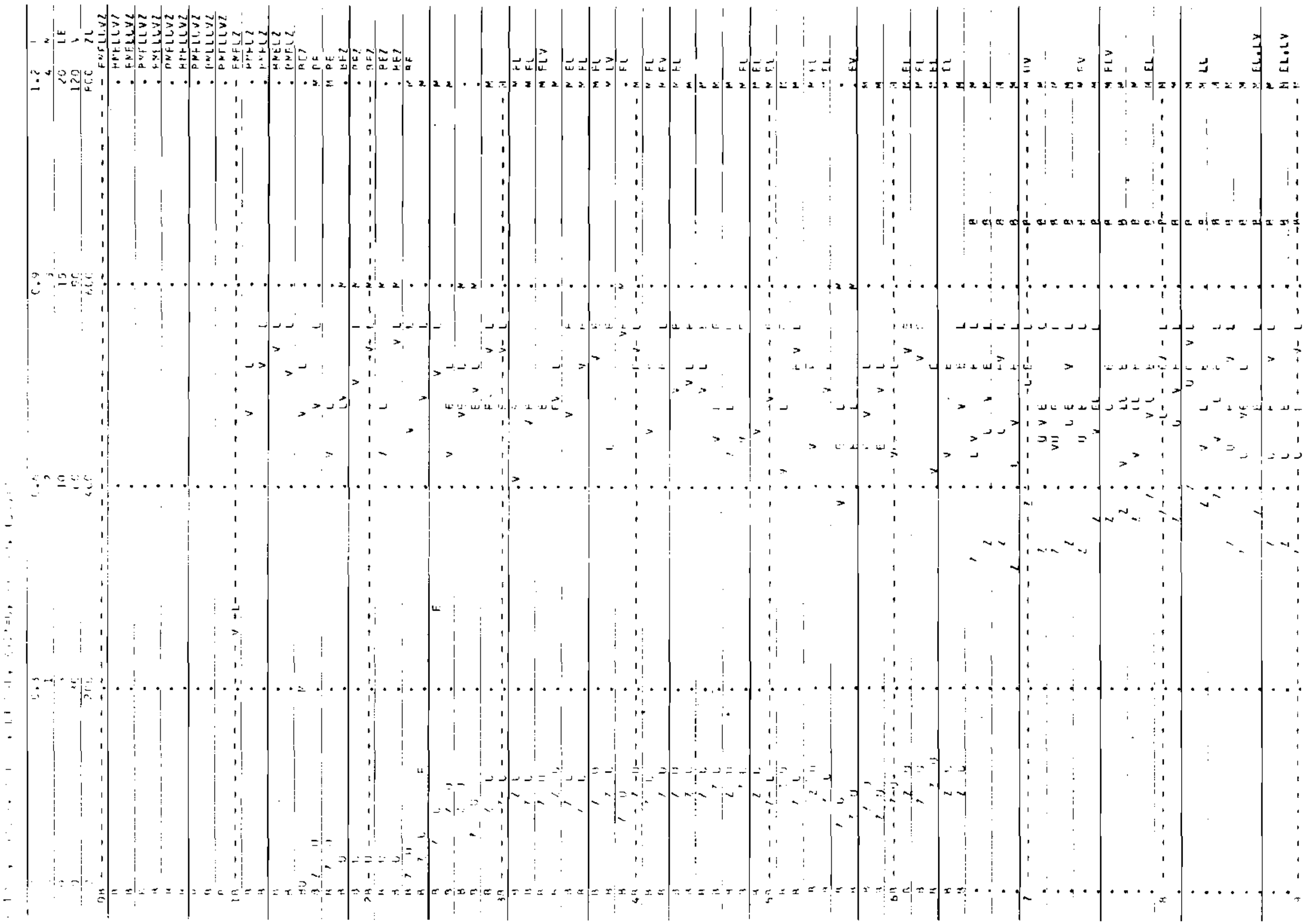
Flow Diagram Changes, Model IV



Flow Diagram Changes, Model V



Flow Diagram Changes, Model VI



Example Plot 3, Variables of Interest

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